# NBS-GCR-82-399

# An Investigation of the Water Quality and Condition of Pipe in Existing Automatic Sprinkler Systems for the Analysis of Design Options With Residential Sprinkler Systems

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**U.S. DEPARTMENT OF COMMERCE**
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## Notice

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FINAL REPORT

# AN INVESTIGATION OF THE WATER QUALITY AND CONDITION OF PIPE IN EXISTING AUTOMATIC SPRINKLER SYSTEMS FOR THE ANALYSIS OF DESIGN OPTIONS WITH RESIDENTIAL SPRINKLER SYSTEMS

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# ABSTRACT

## AN INVESTIGATION OF THE WATER QUALITY AND CONDITION OF PIPE IN EXISTING AUTOMATIC SPRINKLER SYSTEMS FOR THE ANALYSIS OF DESIGN OPTIONS WITH RESIDENTIAL SPRINLER SYSTEMS

The objectives of this study are defined as follows:

1. To investigate the potential effect of backflow of sprinkler water into potable water;
2. To investigate the potential severity of the pressure reduction due to tuberculation in pipes in residential sprinkler systems.

The first objective is achieved by physical, chemical and biological analyses of water samples extracted from existing automatic sprinkler systems. The latter objective is accomplished by calculating the Hazen-Williams 'C' coefficient associated with a measured water flow rate and pressure differential along a sprinkler pipe. Specific sprinkler systems and locations for sampling are selected to provide a wide variety of conditions for the project relative to the study parameters of pipe material, age, size, and network configuration.

In particular, this study attempts to compare the quality of water in sprinkler system pipes with that from the potable water supply for the building. The detailed analyses allow relevant and significant comparisons to be conducted to potentially assess the necessity for backflow prevention in residential sprinkler systems. Comparison of the calculated Hazen-Williams coefficient with the coefficient associated with new pipe facilitates an approximation of the degree of tuberculation in the pipe. This result provides information to assess the severity of pressure reduction as a function of time as affected by the tuberculation and thus to address the useful life of the pipe.

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# PROJECT BACKGROUND AND SCOPE

It has been postulated that sprinkler systems can significantly reduce the life loss due to fire in residential occupancies (1)*. Intuitively, installation of sprinkler systems would decrease the potential losses from fire in residential occupancies as has been observed in commercial occupancies for almost 100 years.

A substantial amount of research has been conducted in recent years to develop a system which would be more appropriate for residential occupancies by refining the commercial occupancy type of sprinkler system (2). As a result, much attention has been given to the development of a sprinkler system with a more rapid response because of the fire development sequence typically encountered in residences (3). When completed, the outcome of this considerable amount of research should include a set of design parameters for the sprinkler svstem and its installation. The presence of a properly designed system should significantly enhance the level of safety from fire in the residential unit.

The presence of sprinkler systems in various commercial occupancies is typically mandated by building codes or suggested by the insurance industry, rather than by voluntary decision. One major reason for the reluctance to voluntarily include sprinklers in a building is economics. The installation of a sprinkler system involves an additional cost to the construction of a building, despite several design options which become available upon installation of a system.

Thus, in the absence of code mandates or incentives from insurance it is doubtful residential sprinkler systems will gain widespread

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* Numbers in parenthesis refer to references noted as section VII.

acceptance without being inexpensive. This economic constraint has received a significant amount of attention and has formed the basis for the study described in this report.

This study examines the efficiency of one element traditionally required in sprinkler systems and also assesses one parameter which affects the life of a sprinkler system, The efficiency of traditionally required backflow prevention devices is examined, as suggested as a topic for future research in a previously conducted study *(4)*. In addition, an analysis is performed on the extent of tuberculation and corrosion of existing sprinkler system piping, which directly affects the useful life of the pipe and thus of the sprinkler system.

Numerous similar studies examining water quality and extent of corrosion have been conducted in the past. As is indicated in section 2 of this report, the conclusions derived from these studies are not in complete agreement. Thus, the primary objective of this project was to objectively re-examine the problem through a diverse series of tests. As a result of these tests, preliminary information was assembled to understand the magnitude, rather than the specifics, of the problem.

# II RESEARCH PLAN

## 2.1 Site Selection

The initial task of this study included the identification, inspection and evaluation of existing automatic sprinkler system cross-connections with potable water supplies within the Metropolitan Baltimore, Maryland and Washington, D.C. area. Emphasis was placed on locating these cross-connections in residential occupancies. These identified installations were categorized on the basis of pipe materials. Initially, three materials were targetted for consideration; black steel, copper and PVC plastic piping. Additional design factors were considered for selection of the specific sprinkler systems for use in this study. These factors included parameters such as:

-pipeline age
-pipeline installation technique
-pipeline dimensions (length and diameter)
-pipeline network configuration (loop versus dead-end)
-case/accessibility for sampling and testing
-potable water source
-potable water characteristics
-prior system use (flushing or discharge due to fused head)

After reviewing these parameters, representative systems for each of the three targetted pipe materials were selected as potential sites for further water quality evaluations. The net objective of the selection process was to include a varied assortment of installations representing a wide gamut of conditions. Water from a small group of locations was resampled near the end of the study after having been disturbed approximately six to seven months earlier, in the initial sampling phase, to investigate the transient behavior of water quality and corrosion.

## 2.2 Water quality Evaluation

A characterization of water quality within automatic sprinkler system piping necessitated the withdraw1 of sample aliquots from representative sprinkler systems. These samples were then tested according to phvsical, chemical and biological parameters appropriate to the desired quality evaluation. The specific tests are described in section III of this report. The specific variables considered in the selection of appropriate sprinkler systems for the water quality analysis included: pipe materials, system age, usage or flushing history, site location and ease of samplinn.

## 2.3 Hydraulic/Hazen-Williams Coefficient Evaluation

The friction loss characteristics were determined through performance of a flow test and subsequent calculation of the Hazen-Williams 'C' coefficient. Due to the availability of sprinkler systems for the water quality analysis, this additional test was considered to be efficacious and would supplement the existing data base.

Appropriate locations were selected for the flow tests to evaluate the Hazen-Williams 'C' coefficient. The criteria for selection were similar to those previously listed in section 2.1 with additional emphasis on the pipeline configuration. The required configuration consisted of a pipeline of constant diameter between two pressure measurement points with a capability to flow water from the end of the pipeline.

## 2.4 Operational Definitions

Residential Occupancy: "Are ones in which sleeping accomodations are provided for normal residential purposes and include all buildings designed to provide sleeping accomodations". (5, section 4-1.6).

Sprinkler System: "A system of pipes tubes or conduits provided with heads or nozzles, that is automatically activated by the sensing of heat, to distribute water and water based extinguishing agents in the fire area". (5, p. 52)

## 2.5 Study Limitations

1. The original project intent of obtaining samples and performing tests through out the Baltimore-Washington, D.C. area was modified due to the general unavailability of existing sprinkler systems for analysis. While numerous sprinkler systems were present in residential occupancies in the region, building owners and managers typically were reluctant to voluntarily permit access to the research team. Thus, the wide variety of sprinkler systems intended to be analyzed could not be obtained, thereby primarily restricting the research team to the College Park Campus of the Universitv of Maryland.

2. Sprinkler systems could not be disconnected from service for any lengthy duration, thereby restricting any testing to those tests which could be expediently performed.

# III LITERATURE REVIEW

## 3.1 Water Quality Background and Considerations

Aside from providing sufficient availability, a water distribution system must also furnish an aesthetically pleasing flow of potable character. The introduction of sub-standard waters into these networks, either by intention or accident, would therefore be unacceptable. Cross-connections, backflow and back siphonage have, however, historically been linked with this type of water quality deterioration.

The original classic case of a calamitous cross-connection occurred in 1903 at Lowell, Massachusetts during a fire fighting operation (7). A pressure drop in the potable line resulted in back-siphonage through the fire-hoses which severely contaminated the main water supply. Subsequent repetitions of similar fire-related cross-connection incidents eventually led to the development and enforcement of preventative measures to safeguard against such hazards (8-10). These measures primarily revolved around the installation of check values (i.e. single, double, alarm, etc.) on fire sprinkler lines to prevent the introduction of sub-standard waters.

Another historical problem for water distribution lines is that of dead-end mains. Potable water distribution networks may have remote lines which are rather isolated and not well connected to any extensions (11-13). The restriction of circulation in these dead-ends may lead to a depletion of residual chlorine and consequent bacterial growth. The hazard arises when backflow occurs, i.e. when a pressure drop in the main line produces back-siphonage. Potentially contaminated water perhaps including either unwanted bacterial levels or noxious chemicals, may then flow into the potable line. In turn, such mixing could lead to undesirable deterioration of the existing water quality. For this reason, the design of contemporary distribution systems specifically seeks to avoid these dead-end zones (11-13). Routine flushing is generally employed to minimize any such potential for stagnation in possible dead-end areas.

The desire on the part of water supply engineers to avoid incorporating dead-end lines in water distribution networks can be well-documented. Hardenbergh states that dead-end water lines become stagnant and allow sediment to accumulate *(14)*. Aside from the potential effect on the potablecharacteristics of the primary network, the sediment may potentially constrict and clog the sprinkler head itself to the point where the device might fail to provide water in the proper quantity and distribution. Wegmann's account regarding the design of water supply networks in the major cites of the U.S. uniformly notes the absence of dead-end lines (15). And more recently, Al-Layla, Ahmad and Middlebrooks again reinforced the notion that engineers should avoid dead- en^ piping (13). They state that such dead-end zones should be provided flushing hydrants to allow the line to be occasionally cleaned out.

In the case of cross-connection hazards, the problem is that of introducing sub-standard or contaminated waters from a source outside the original pipe network. There is certainly no argument regarding the necessity of eliminating such hazards.

Considering backflow or back-siphonage, the source of the potentially contaminated waters may eminate from isolated dead-end zones within the network itself. These dead-ends may be eliminatedbydesign or routine flushing. However, the circumstance of fire sprinkler lines as dead-end zones represents an inexact concern. The determination of whether backflow prevention is necessary on sprinkler piping hinges upon the potential for unacceptable contaminant buildup within these lines.

It should be noted that a typical dead-end piping zone in a potable system may involve several hundred or thousand feet of pipe, at diameters exceeding several inches. Accordingly, the water volume and interior pipe surface within this zone is rather considerable. While perhaps spanning similar lengths, a commercial sprinkler system would contain considerably less water. With its reduced diameter, the interior wall surface available for bacterial attachment and metal leachate also is reduced.

For an envisioned domestic sprinkler system without a storage tank, the contained water and pipe surface would be substantially further reduced. Given that these latter residential systems would likely be isolated from external connections, the primary concern would therefore revolve around the impact of backflow. The potential for contaminant buildup in domestic fire sprinklers must therefore be addressed, as an assessment of theefficiencyfor backflow prevention.

## 3.2 Varied Perspectives on Requiring Backflow Prevention

Existing federal policy, as stated by the Safe Drinking Water Act of 1977, requires that backflow prevention will be provided on all cross-connections linking potable and non-potable water (16). In the particular instance of domestic fire sprinkler lines, though, debate may address the issue as to whether these lines contain non-potable waters. Additional support for the implementation of backflow prevention is also provided by the National Fire Codes, as promulgated by the National Fire Protection Association (NFPA). In this case, the installation of check valves on single-family sprinkler lines directly connected to a potable line is specifically required by NFPA 130, "Standard for Installation of Sprinkler Systems in One- and Two-Family Dwellings and Mobile Homes" (5).

Another view point on backflow prevention is that provided by the American Water Works Association (AWWA), representing officials responsible fox ensuring the protection of potable water distribution systems. The AWWA subcommittee on Cross-Connections has formulated a standard manual, "Recommended Practice for Backflow Prevention and Cross-Connection Control" (M14) covering the necessity for backflow prevention equipment (17). M14 identifies six classes of water supplies relative to fire protection and recommends the degree of backflow prevention necessary for each class. Class 1 and 2 apply to the circumstance appropriate to the types of sprinkler systems being contemplated for single-family dwellings (i.e. directly connected to the public main; no tanks reservoirs, no other physical connections, no antifreeze discharge to the atmosphere and/or safe outlet, with or without a booster pump). For these categories, M14 recommends that no backflow prevention is necessary. These latter two positions, as presented by NFPA and AWWA, are somewhat dichotomous, in that the group responsible for water quality, i.e. AWWA, is actually more lenient towards stipulating backflow prevention requirements for sprinkler systems in single-family/residential locations. In addition, the M14 policy does establish a precedent against a consistent, conservative requirement for backflow prevention.

Arguments against the necessity for backflow prevention in fire sprinkler systems have also been offered by various interested individuals and groups (18-20). Mulrine stated that the sprinkler industry had been unable to establish a case where water contarnination resulted from the backflow out of an automatic fire sprinkler system (18). This reference also cited a one year study conducted by the San Diego Utilities Department comparative testing of water mains and sprinkler line water found no significant quality difference. Consequently, their particular requirement for a single detector check valve was revoked, following these findings. Also, Mulrine alluded to the negative findings of a similar study by Agri-Science Laboratories, Inc. (10). In this case, Agri-Science tested sprinklers at three locations: a meat packing plant, convalescent home and a small industrial building. Results of the study showed some variation from the potable water line, but nothing was observed that would indicate the risk of potential harm to the potable water supply. However, it should be noted that their analyses did not include coverage of the more critical heavy metal species, such as lead, nickel, chromium, cadmium, etc.

A legal precedent for discontinuing backflow prevention requirements was also established in 1973 by the Supreme Court of Utah (20). Their conclusion was based on the rare possibility of harm from unchecked sprinkler systems compared to the expense and complications associated with installing these backflow preventers.

The National Automatic Sprinkler and Fire Control Association (NASFCA) has further contested "blanket" backflow prevention regulations, arguing for the adoption of a slightly modified version of the AWWA's M14 policy (21). In this manner, NASFCA felt that the enforced requirements would be appropriate to the arrangement of the sprinkler system and the domestic water line. The suggested alterations to M14 primarily centered around changes in permissible water storage. These suggestions were supported by reference to the Agri-Science and Utah Supreme Court findings, as well as to a Metcalf and Eddy report on the long-term quality of stored water (22). This latter report indicated that water storage up to 2 years in wooden and steel containers had no adverse impact on the water potability, based on its bacterial content. Subsequent reply to these NASFCA suggestions from the M14 committee, however, essentially indicated an unwillingness to revise the existing M14 standard (23).

### 3.3 Mixing Aspects of Fire Sprinkler Water and Potable Water

As noted in the previous two sections, numerous studies have been conducted relative to the quality of water in sprinkler systems compared to potable supplies. A key issue which has not received much attention is the degree of nixing of the water in a sprinkler system and the potable water in the domestic piping. In the case of the larger commercial industrial sprinkle system, there is general acceptance that stagnation does occur. However, these lines are considerably longer and backflow check valves are involved.

For the domestic systems, the fact that the involved pipe lengths are reduced may be offset by the concomitant reduction in pipe diameter. Simple mixing action generated by flow in the potable line past the sprinkler line connector would therefore not likely extend significantly beyond the immediate connection zone. Draw-downs on the potable systems could cause considerably greater flushing of these sprinklers. However, these draw-downs are generally infrequent for most residences. Even if the homeowner was requested to do so routinely, it is probably unlikely that such draw-downs would reliably flush these lines.

The final impact on sprinkler line mixing would be that of the water hammer effect. As a member of the AWWA Subcommittee or Cross-Connections, Norseth (23) has indicated that most fire sprinklers contain air pockets at their high points which fluctuate in volume with line pressure. Being unable to vent or blow off collected air from the attached head, the formation of these air pockets is expected. Whether by design or coincidence, these bubble zones would. act as shock absorbers to dampen the hydraulic surge of a water hammer. In fact, vertical plumbing risers or air chambers, hydraulically comparable to the envisioned sprinklers, are commonly recommended to counter this water hammer phenomenon *(24)*.

Under these conditions, the water level within the sprinkler lines could be expected to surge back and forth in order to dampen water hammer shocks. These surges could considerably improve mixing along the line, perhaps to the point of effectively negating any contaminant buildup. There are certain unknowns about the particular usefulness of this mechanism, though, These include the complexity of multiple sprinkler line attachments, and of their respective positioning away from the initial potable line connection,

The degree of mixing available within residential fire sprinkler lines represents a critical issue in the determination of backflow prevention requirements. Further detailed research on this topic is necessary.

### 3.4 Water Quality Aspects of Static Fire Sprinkler Waters

Obviously, water quality conditions within a fire sprinkler line depend upon the involved residence time, Systems receiving adequate mixing action, such as that discussed for the possible water hammer effect, could be expected to contain water reasonably equivalent to the original potable supply. At the other extreme, water stagnated in a line for months, years or decades could encounter varying degrees of deterioration.

In the event that stagnation does occur, a complex set of physical, chemical and biological reactions would be initiated. While some of these reactions affect only the aesthetic quality of the water, others affect potability. This latter concern unquestionably represents the pivotal issue surrounding the efficie'ncyforbackflow prevention devices.

Health hazards relating to such stagnated water will stem from either biological or chemical agents. The biological activity in such isolated lines nay be linked to a reduction in residual chlorine presence. Having originally been added as a disinfecting safeguard, these chlorine species are chemically unstable and will diminish with time. Lacking such chlorine, dead-end zones have reportedly become contaminated with high coliform concentrations (25). These coliforms are regarded as indicator organisms, pointing towards the possible existence of disease - causing pathogenic bacteria.

Recently obtained evidence, however, indicates that even the potable pipelines themselves may be contaminated with microorganisms (26,27). In particular, plating studies and scanning electron microscopy has revealed considerable microbial growth within the isolated microenvironments afforded by wall occlusions and tubercles (26, 28). Hence, the sterile conditions oftentimes presumed to exist with these potable networks appears to be an optimistic fallacy.

In regards to the speciation of the mocroorganisms found in these potable lines, numerous investigators have identified Aeromonas, Streptococcus, Pseudomonas, Viblio, Staphylococcus, Candidus, Myconacterium and Salmonella, in addition to those bacteria traditionally classified as Coliforms (27). Numerous other life forms associated with the availability of specific chemical substrates have also been detected. These include various iron bacteria (i.e. Gallionella, Desulfovibric, Thiobacillus) (29). Herman also observed the development of pigmented, slow-growing bacteria (i.e. Xanthomonas, Cvtophoga, Psendomonas, Aeromonas and Flowobacterium) in water systems, particularly in static locations such as water fountains, humidifiers and the like (30).

For the most part, these mocroorganisms are not particularly hazardous. However, certain of the genus categories do contain pathogenic species (e.g. Vibrio Cholera).

Overall, it is doubtful whether a complete enumeration could be developed for all life forms likely to be found in potable water lines. Given that microbial activity in these lines is evident, though it is consequently reasonable to expect similar metabolism in attached fire sprinkler lines. The important concern is therefore whether these organisms and particularly the pathogenic segment, magnifies in concentration within these sprinkler lines to the point of creating a hazard. Unfortunately, the literature provides virtually no concrete evidence or answers to this question.

In the event that stagnation does occur in the sprinkler lines, it is reasonable that oxygen tension would be diminished similar to chlorine. The introduction of organic substrates into these stagnated zones would also be restricted. Hence, bacterial activity would have to exist under anaerobic conditions with essentially no replentishment of depleted organics. Some type of cutting oil (i.e. hydrocarbon) deposit may be present due to its initial use during the installation of the sprinkler line (i.e. in the case of steel lines requiring threading). However, hydrocarbon degardation under anaerobic conditions would not be considered an environs capable of supporting luxurious bacterial growth.

Additional autotrophic bacterial activity may be envisioned for those mocroes capable of extracting energy from metabolism of iron, manganese, sulfur or nitrogen materials. However, these latter bacteria are generally not categorized as pathogens. Hence, a theoretical consideration of long-term bacterial activity in domestic fire sprinklers does not lend strong support to the possibility of hazardous bacterial growth.

Perhaps more of a concern, though, the envisioned bacterial activity could stimulate corrosion of the pipe wall (31). Indeed, Lee et.al. found that microbial activity promoted localized corrosion through tubercle formation (31). Chemical conditions within these sprinklers might also favor such corrosion, i.e. reduced pH, low buffer capacity, low hardness, etc (32). In either case, accelerated corrosion would not only reduce the effective lifetime of the pipe, but also increase the level of metal leachate reaching the contained water. In some instances, overnight standing residence samples have reportedly contained lead and cadmium levels which exceed the Maximum Contaminant Level (MCL) established by the Safe Drinking Water Act (16, 32). While these situations may represent an extreme, metal leachate must be recognized as a potential concern for stagnated sprinkler water,

### 3.5 Friction Loss Characteristics of Pipe

As is well known, the frictional resistance of fluid flow in conduits is dependent on numerous variables. One frequently noted variable is the interior surface characteristics of the conduit. These characteristics include the geometric configuration of the bounding wall as well as the texture of the wall. In automatic sprinkler systems the geometric configuration is nominally constant, i.e. the interior surface is circular. However the texture or smoothness of the interior surface of the pipe is known to vary significantly between systems, primarily due to the phenomenon of corrosion. Corrosion causes the interior surface to become more rough, thereby increasing the frictional resistance to fluid flow, In some cases, products of corrosion have accumulated in the interior of a pipe to effectvely reduce the pipe diameter or possibly to completely closs the pipe.

This section reviews the conclusions obtained from previously conducted studies relative to the phenomenon of corrosion in water piping systems. The following section addresses the effort expended in this study relative to corrosion as it affects the interior surface of existing automatic sprinkler systems.

#### 3.5.1 Basic Concepts of Corrosion

Corrosion is an electro-chemical type of reaction. In water piping systems, the reaction can occur if the pipe material contacts a dissimilar metal, which may be a component of the water piping system, or may be either water soluble or water-borne. The undesirable result of the contact is the slow consumption of the pipe material. The consumed pipe material may be carried away by the water flow or accumulate on the interior surface of the pipe increasing the roughness of the surface. After a significant period, the corrosion can:

1) Cause the pipe interior to become clogged, thereby restricting flow, or 2) cause portions of the pipe walls or joints to be consumed, thereby allowing leakage (40).

Six types of corrosion typically encountered in water piping systems are described below (41, 42).

<u>General Corrosion</u>: Reaction of exposed areas of pipe metal by anodic dissolution.

<u>Galvanic Corrosion</u>: Reaction occurs at point of contact between two dissimilar metals, e.g. connection of copper sprinkler line with galvanized steel domestic cold water line connection of brass sprinkler head with galvanized steel sprinkler pipe, etc. The more electronegative metal is consumed by this process.

<u>Erosion Corrosion</u>: Phenomenon occurs as a result of abrasive action by water-borne particles flowing along pipe wall. This type of corrosion is prevalent in system with continuously flowing water, thus is of minimal concern in automatic sprinkler systems.

<u>Concentration Cell Corrosion</u>: Localized reaction caused by the creation of an electromotive potential as a result of the depletion of oxygen. This type of corrosion is more severe in cases of very low or no flow of water, e.g. automatic sprinkler systems.

<u>Microbiological Corrosion</u>: Reaction caused by micro-organisms either directly or indirectly. The bacteria can be sulfate-reducing, iron or manganese bacteria. Tuberculation can be caused by the deposits of these bacteria. This type of corrosion increases with increasing flow, thus should not be significant in automatic sprinkler systems.

<u>Pitting Corrosion</u>: Phenomenon may be caused by any of the above reactions and is specifically identified by the formation of tubercules. Prior to the actual formation of tubercules are the creation of "blisters" composed of iron oxide, in the case of ferrous pipe materials which cover the pits in the pipe interior wall surface, eventually growing to become tubercules.

### 3.5.2 Parameters Affecting the Rate of Corrosion

As noted in the preceding descriptions of the various types of corrosion, the water flow rate and frequency is known to significantly influence the rate of corrosion as well as the prevalent mode of corrosion. In general if the water is stagnant, the process of corrosion is capable of being localized with the products of the process being permitted to accumulate. If the water is flowing, the process of corrosion generally will effect larger areas with the products of corrosion being flushed by the water. The result of removing the products by the flowing water is the exposure of new pipe material as well as to add abrasives to the water, affecting pipe material downstream.

Another key variable influencing the rate of corrosion is the pipe material. Certain materials are more vulnerable to corrosion, requiring some means of protection. This is discussed in more detail in the following section.

Numerous other parameters have also been identified as being influential on the corrosion rate *(41, 43-46)*. These parameters are categorized by Thompson as follows:

water quality

distribution system

service conditions

pipe quality

The quality of the water contained in the pipe is one category identified as being of primary importance. A comprehensive discussion of the quality of water in automatic sprinkler systems as surveyed in this study was presented in previous sections. A corrosion index presented by Riddick relating the ability of water to promote corrosion is determined through a semi-empirically based equation. This equation contains many (8) of the variables included in the analysis phase of the study previously described in this report.

$$\text{Corrosion Index} = CO_2 + \tfrac{1}{2}(\text{Har.} - \text{Alk.}) + Cl^- + 2N \frac{75}{\text{Alk.}}$$

Where:

**Har:** Hardness

**Alk:** Alkalinity

$CO_2$: Carbon Dioxide Content

$Cl^-$: Chlorine ion content

N : Nitrate Content

In addition to five properties contained in Riddick's equa ion, other water quality properties such as the electrical resistivity, dissolved gas content (especially oxgen), metals content, anion and cation presence, pH and temperature have been identified as impacting the corrosion rate *(41, 43-47)*, though not through the use of an equation.

The variables contained in the distribution system category relate to physical features of the system. Included in this category are variables related to the design and configuration of the system. In addition, the type of system, e.g. domestic water line, automatic sprinkler system type (wet or dry), etc. is considered by this category. The frequency of use is another variable related to the distribution system which influences the corrosion rate, as well as the mode of corrosion, as noted in the previously presented descriptions of the corrosion types or modes.

The service conditions of the system also effect the corrosion rate. These conditions consider maintenance programs, ambient conditions, etc.

The fourth category of variables considers the pipe condition. This category is concerned primarily with quality control of the pipe at the time of manufacture. As an example, discontinuity of a protective coating applied to a pipe material makes the pipe susceptible to rapid deterioration through corrosion.

### 3.5.3 Pipe Materials versus Corrosion Rate

The relationship of pipe material and the rate of corrosion has received a significant amount of attention in past research efforts *(43, 47-52)*. Several of the past projects have analyzed the relationship by comparing the change in the corrosion rate by changing only the pipe material while maintaining all other parameters constant. Copper and steel are two piping materials which have been compared in several of the previous projects.

The corrosion of copper pipe occurs immediately, upon contact with water (47). However, after this immediate contact, a protective film forms, thereby inhibiting further corrosion (52). Thus, sources typically classify copper as corrosion resistant. The corrosion rate for copper has been measured by Nelson *(49)* as 0.902 inches per year for water of approximately pH 7. Two key water quality parameters which have been shown to substantially increase the corrosion rate of copper pipe are the pH and carbon dioxide content.

Unlike copper which only has one actual stage of corrosion, galvanized steel pipe has two stages of corrosion, as identified by Riddick (47). The first stage is characterized by the gradual removal of the protective coating of zinc and is known as dezincification. The second stage includes the attack of the water directly upon the steel, after the protective coating in an area is completely removed. The corrosion rate of steel is known to be strongly dependent on the pH of the water as well as other water quality paramters *(46)*. For a pH near 7, the corrosion rate is 0.02 to 0.05 inches per year, increasing inversely with the pH **(39)**. Because of this high rate of corrosion, federal, provincial and local authorities in Canada and some local authorities in the U.S. have banned the use of galvanized steel.

The protective coating of zinc acts to protect the steel through the formation of oxide or carbonate compounds of zinc. Carbon dioxide has been shown to adversely affect the zinc coating. This coincides with the conclusions of an American Iron and Steel Institute Committee in 1949 suggesting the reliability or life of a protective coating for steel strongly depends on the water conditions. In addition, the susceptibility of steel corrosion has been determined to be essentially independent of the carbon content of the steel.

Thus, the comparison between copper and galvanized steel appears relatively clear, especially for systems with continually flowing water. Considering the effects of corrosion the useful life of galvanized steel pipe for these systems is estimated between 20 to 25 years *(48)*. Copper is categorized as "corrosion resistant", thus the life is theoretically infinite. However, for systems with stagnant water, e.g. automatic sprinkler systems, the rate of corrosion for galvanized steel significantly decreases approaching the corrosion rate of copper. This was noted by Godard as follows. (52, p.4)

> "Another example of negligible corrosion rates in stagnant water systems is wet type fire prevention sprinkler systems which are kept filled with water under pressure at ambient temperatures. In the absence of oxygen, even galvanic corrosion between brass sprinkler heads and steel pipe is usually negligible."

### 3.5.4 Experimental Technique to Measure the Extent of Corrosion

The extent of corrosion in pipe systems has been measured in two previous studies through correlation with the 'C' coefficient in the Hazen-Williams equation. The premise upon which this technique is based is: the more extensive the corrosion, the rougher the interior surface of the pipe. As is well known, increasing the roughness of the interior pipe surface decreases the value of the Hazen-Williams coefficient.

Hudson first documented this technique to measure the severity of corrosion by determining the 'C' value in a municipal distribution system in the 1960's (53). Grinnell also utilized this technique in 1968 for testing the extent of corrosion on automatic sprinkler system piping (54).

The Grinnell tests were performed on steel piping of 1, 1½ and 2 inch nominal diameters. Pipe samples were removed from six automatic sprinkler systems located in six cities in the United States. The pipe samples then were installed in the Grinnell Laboratory at Providence, Rhode Island.

The measurement system for the tests consisted of pressure taps connected to differential manometers and an orifice meter to measure the flow rate. The samples were further prepared by removing heavy accumulation of rust and scale which would have been removed by the water flow and possibly clog the pressure taps.

The actual testing consisted of measuring the differential pressure loss for a specific water flow rate. This procedure was repeated for several flow rates to improve the reliability of the accumulated data. The 'C' values were then calculated by a graphical technique and related to the age of the pipe, type of system (wet or dry) and other parameters.

# IV RESEARCH METHODS

## 4.1 Procedure for the Selection of Systems

The selection process of sprinkler systems for this study was similar for both the water quality and flow test phases. The following three variables influenced the selection of systems:

1. occupancy of the building in which the system is contained.
2. diversity of sprinkler systems' parameters.
3. availability and accessibility of the system.

Since the intent of the study was to investigate the properties of sprinkler systems for application to the concept of residential sprinklers, emphasis was placed on including sprinkler systems in this occupancy class. It was not expected that the stagnant water in a sprinkler system was dependent on the occupancy of the building, but rather the investigators chose to avoid a potential area of criticism by concentrating on sprinkler systems in residential occupancies.

As previously noted, the objective of this study was to accumulate some data to investigate "the magnitude of the problem". As such, it was apparent that including a wide diversity of systems was desirable. Thus, systems were selected to include various combinations of the following parameters:

- Pipeline age
- Pipeline installation technique
- Pipeline dimensions/configuration relative to the dead-end position
- Ease of sampling
- Potable water source
- Potable water characteristics
- Prior system use
- Category of installations by occupancy

Lastly, consideration was given to the availability and accessibility of the sprinkler systems for analysis. Due to the relative unavailability of sprinkler systems not located on the

College Park Campus of the University of Maryland, a significant majority of the tests were performed on campus (see Appendix A for specific locations). In addition to the availability, system accessibility was important, especially for the flow test phase. For this phase, the system had to be capable of being slightly modified for the test, as is described later In this chapter.

Sampling of water and flow testing was initiated in March, 1980 and completed in November, 1980. All of the flow tests and all except four of the water samplings were conducted in buildings, on or associated with the Universityof Maryland College Parkcampus. All of the University sprinkler systems are properly maintained with flow tests performed approximately on an annual basis. Pipe materials were either copper or steel for all systems included in the study. The maximum age of any system included was approximately 19 years with an average age of approximately 9 years.

4.2 <u>Water Sampling Procedures</u>

The selected fire sprinkler systems were tested at one of two positions: the inspector's test site or an existing sprinkler head. Either location had its particular advantages and disadvantages. An inspector's test site, as depicted by Figure 1, was generally more accessible and easier to sample. However, the associated outlet valve was typically set back a considerable (e.g. 5 to 6 ft) distance from the actual outlet unlike that depicted by Figure 1. Desired preparation and sterilization of the complete outlet line was therefore a significant problem with these locations,

The remaining water samples were taken from in-line sprinkler heads, such as that shown by Figure 2, In this case, controlled discharge

Figure 1. Typical Inspector's Test Site for Water Sampling

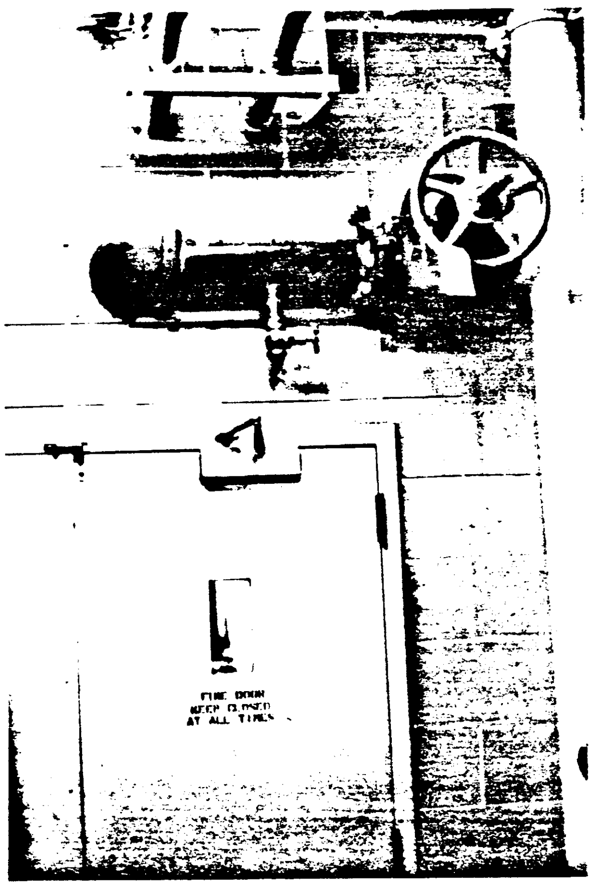
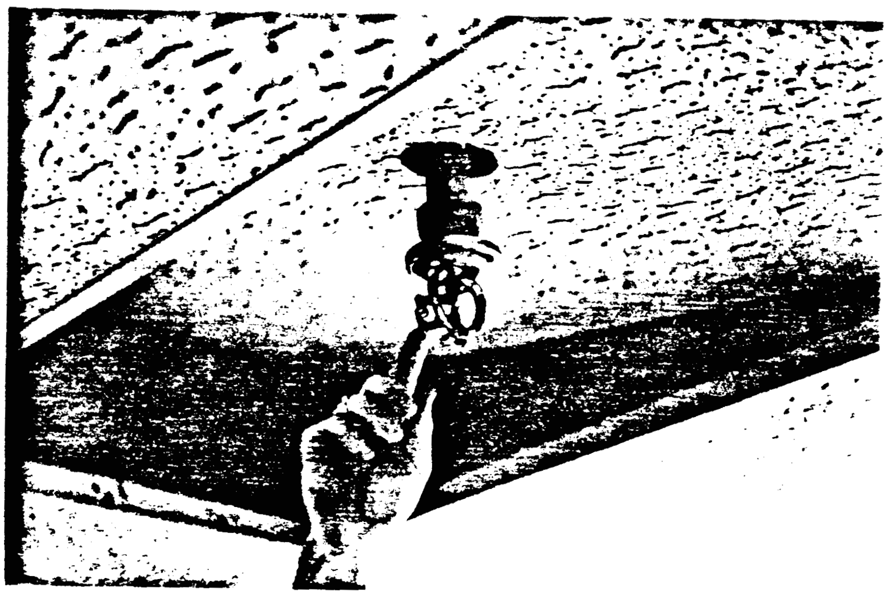


Figure 2. Typical Sprinkler Head Site for Water Sampling



of the water from the line was noticeably more difficult, Water pressure within the sprinkler system, combined with the awkward and imprecise unscrewing of the head, frequently complicated the sampling effort. Twice, accidental removal of a head caused considerable flooding.

The potential for sterilization of the sprinkler head was somewhat better than that available at the inspector's test. Testing at the pendant sprinkler heads allowed water to flow down the actual head rather than on the pipe as in the case of upright heads. However, the complex sprinkler head configuration did introduce an uncertainty about the actual degree and completeness of sterilization, Overall, though, either sampling location was considered to provide an adequate test specimen.

The first step in procuring the sprinkler water samples was that of cleansing and sterilizing the sampling location, This sterilization was important to the validity of the biological water analyses. The applied routine consisted of an initial ethanol wash and scrubbing, serving both to cleanse and sterilize the site, Figure 3 demonstrates this activity. Ethanol was also applied from a squirt bottle, particularly when recessions or crevfces were evident. Finally, the sterilization procedure was concluded with an acetone swabbing (*see* Figure 4), followed by a short vaporization period, Consideration was given to a further irradiation step, However, the obtained analytical results did not appear to warrant such a measure. While the sample site was being sterilized, the involved sprinkler line alarms were deactivated, The line was also isolated at this time by closing down the main water valve,

Immediately following the site sterilization, an initial 500 ml

**Figure 3. Sampling Site Cleansing/Sterilization with Ethanol**

Figure 4. Sampling Site Swabbing with Acetone

water sample was collected in a pre-sterilized glass bottle During the collection of this sample, as depicted by Figure 5, every effort was made to minimize potential contamination. On occasion though, it was readily evident that the sprinkler line was not adequately pre-sterilized. As a case in point, an inspector's test site yielded a cockroach during this initial sampling. Such observations were fortunately uncommon.

Figure 6 depicts the subsequent collection of a general 1500 ml water specimen, also using a glass bottle. When possible, control samples were taken from the proximity of the test site. These controls were usually obtained from nearby bathroom water faucets, These latter samples provided a quality control check, particularly on the sterilization measures. The controls also established a baseline for comparison with the sprinkler data. As with the sprinkler lines, two control sample aliquots (i.e. 500 and 1500 ml) were collected for the general and biological analyses.

## 4.3 Water Analysis Procedures

Table 1 summarizes the parameters and related procedures which were used to evaluate the obtained water samples, 'In general, these analyses conformed to the methodology established by Standard Methods (33) of the U.S. Environmental Protection Agency. (34)

Color, odor and turbidity measurements were qualitatively assayed immediately following the collection of the water samples. Both sample aliquots (500 and 1500 ml) were then returned to the Environmental Engineering Laboratories of the Department of Civil Engineering, University of Maryland.

Upon arrival at the lab, the biological analyses were also conducted immediately using the 500 ml aliquot, In the event that

Figure 5. Collection of Initial Sample Aliquot in Sterile Glass Bottle

Figure 6. Collection of General 1500ml Sample Aliquot

TABLE 1

Water Quality Parameters and Procedures

| Parameter | Analytical Method | Reference(s) |
|---|---|---|
| Physical | | |
| Color | Visual | - |
| Odor | Olfactory | - |
| Turbidity | Visual | - |
| Suspended Solids | Gravitimetric | 33 |
| Chemical | | |
| pH | Calibrated pH Meter | 33 |
| Alkalinity | Acid titration | 33 |
| Specific Conductance | Wheatstone bridge | 33 |
| Sulfate | Turbidimetric | 33 |
| Chloride | Selective ion electrode | 39 |
| Ammonia | Selective ion electrode | 35 |
| Nitrite | Selective ion electrode | 39 |
| Nitrate | Selective ion electrode | 39 |
| Chemical Oxygen Demand | Potassium dichromate | 33 |
| Heavy Metals | | |
| -Copper (Cu) | Atomic Absorption | 33 |
| -Chromium (Cr) | Atomic Absorption | 33 |
| -Cadmium (Cd) | Atomic Absorption | 33 |
| -Iron (Fe) | Atomic Absorption | 33 |
| -Lead (Pb) | Atomic Absorption | 33 |
| -Nickel (Ni) | Atomic Absorption | 33 |
| -Zinc (Zn) | Atomic Absorption | 33 |
| Biological | | |
| Total Plate Count | Millipore (M-TGE) | 35,36 |
| Fecal Coliform | Millipore (M-FC) | 33,36 |
| Yeast/Fungi | Millipore (M-Green) | 36,37 |

the complementary chemical analyses were not to be tested at this time, the 1500 ml general sample and the 500 ml of filtrate from the biological testing was then refrigerated. A 50 ml portion was also set aside and acidified before refrigeration, This latter sample was used for the heavy metals testing. These preservative measures provided a two day period over which the analyses could be completed.

The biological tests covered the following microbiological groups: total plate counts, fecal coliforms and yeasts/mold. These biological analyses followed an established membrane filtration procedure. (33-35) Selective growth medias appropriate to these three target groups were furnished by pre-packaged nutrient ampules (i.e. Millipore™ MTGE3 (9) for total plate count, Millipose™ M-FC (33,35) for Fecal Coliform and Millipose™ M-Green (37) for the yeast/mold species).

Additional microbiological tests were employed on a random basis to attempt further identification and evaluation of microbial growth observed in the sampled waters, These tests included: Standard plate counts using Tryptone glucose yeast (TGY) agar (33) MacConkeys plate counts for oxidative activity (36), and Enterotube II™ multi-media inoculation tubes for Enterobacteriaceae speciation (38). In some cases, the high solids content of a sample did interfere with the accurate measurement of colony growth on the filtration membrane. Samples which did contain the high solids were therefore comparatively tested with both shaken and unshaken volumes, The heavy metals analyses were also repeated for samples in both the shaken and unshaken state, The major difference encountered for these samples was that of the iron content, probably as a function of rust-type solids suspension.

The heavy metals analyses were conducted on a Varian Mdl., AA-5 Atomic Absorption Spectrophotometer, with a general detection limit of approximately 0.1 mg/l. The ammonia, nitrate and chloride species were all measured with selective ion electrodes (39), which typically were useful and accurate to the sub mg/l range.

Overall, these analytical parameters were collectively expected to provide a suitable quality evaluation of the water retained in the tested sprinkler systems. Comparison of the sprinkler and control water data then provided a suitable characterization of the relative sprinkler water quality.

## 4.4 Procedure Utilized for this Study

After selecting a sprinkler system for the flow test, an appropriate branch line section for the test was identified. An appropriate section was one with at least two sprinkler heads and no change in pipe diameter between the two heads. A typical, appropriate branch line section is presented in Figure 7. The branch line was modified for purposes of conducting the test by replacing the two sprinkler heads with pressure taps. In addition, since a flow of water from the section was necessitated, if an elbow was found at the end of the section, it was replaced by a straight length of pipe. A garden hose was then attached to the end of the pipe section to direct the flow into a calibrated container. A typical branch line section, as modified for the test, with the apparatus is presented in Figure 8.

The tests were conducted as described below. Water was allowed to discharge from the branch line. After the flow reached a steady-state condition, the water flow was directed into the calibrated container. The time was recorded to discharge 20 gallons of water into the container along with the pressure differential between the two pressure taps. Thus, all of the data necessary to utilize the Hazen-Williams equation was accumulated with this relatively unsophisticated system which required minimal time to set up.

Figure 7. Typical Appropriate Branch Line For Flow Test

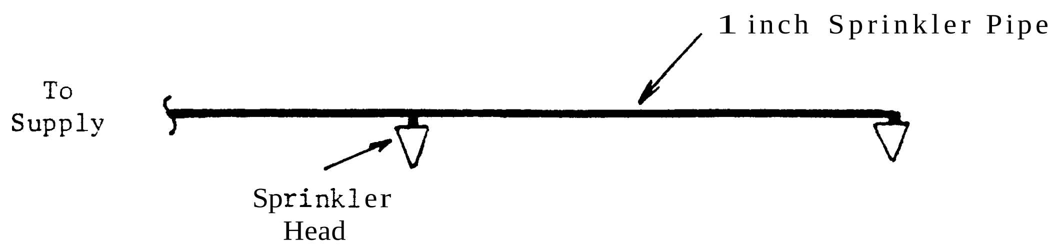
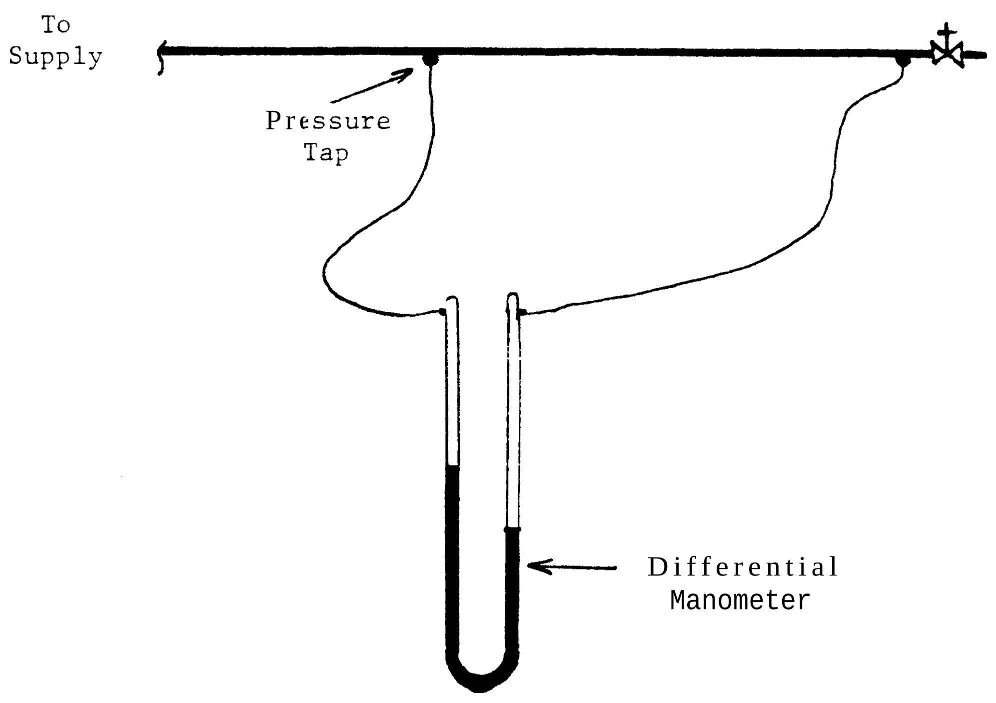



Figure 8. Modified Branch Line For Flow Test



# V. PROJECT RESULTS & DISCUSSION

## 5.1 Introduction

With only four exceptions, all of the tests and samples were conducted on the College Park Campus of the University of Maryland. Whereas each system on the Campus is somewhat unique, the desired diversity of systems obviously could not be achieved. However, the lack of the diversity had the advantage of having control samples of similar characteristics.

## 5.2 Water Quality Evaluation

The following observations were made relative to the water quality evaluations, pertaining to physical, chemical and biological paramters.

### 5.2.1 Physical Parameters

Control

As would be expected, the control water samples were usually devoid of color, odor, suspended solids and turbidity. Occasionally, a mild rust appearance did contribute a slight color and turbidity. The sprinkler lines were, however, found to have considerably different physical parameters. Table 2 provides a comparative summary of the observed physical characteristics, divided between the control samples and the varied types of sprinkler systems (i.e. copper units, steel units and mixed systems). A complete synopsis of the physical parameter data is given by Appendix A.

Copper Sprinkler

The copper sprinkler lines were generally free from color and turbidity. It was not uncommon, though, for these samples to have a considerable dissolved gas release immediately following the withdrawl of the sample. The gas release, and associated turbidity, then dissipated in a matter of minutes. Photographs taken during and after this activity (e.g. approximately 8 minutes apart) are shown by Figures 9 and 10. The fact that the gas did not have a foul odor indicates

TABLE 2

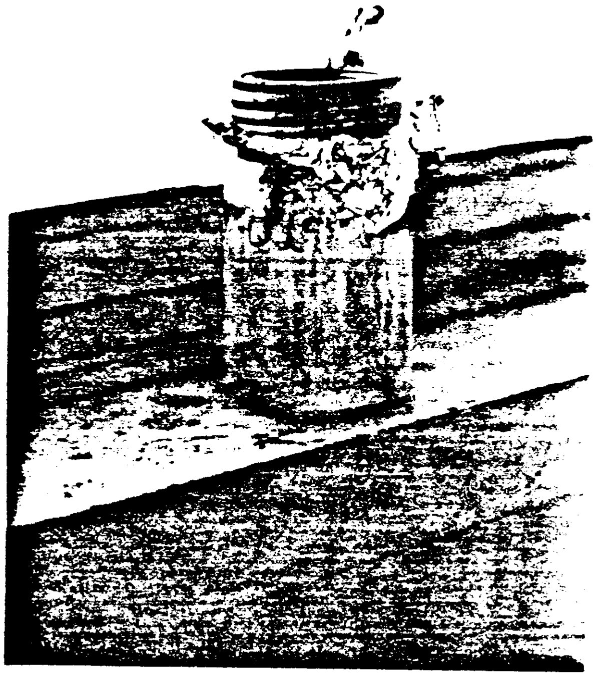
Synopsis of Physical Characteristics Observed
for Fire Sprinkler Line

| | Control (16 samples) | Sprinkler Pipe Material: Copper (Cu) (29 samples) | Sprinkler Pipe Material: Steel (Fe) (25 samples) | Sprinkler Pipe Material: Cu/Fe (2 Samples) |
|---|---|---|---|---|
| ODOR | $\text{None}_{\text{Avg}}$ (None → None) | $\text{Slight}_{\text{Avg}}$ (None → Slight) | $\text{Slightly Oily}_{\text{Avg}}$ (None → Oily/Dank) | Slightly Oily - Oily |
| COLOR | $\text{None}_{\text{Avg}}$ (None → None) | $\text{Slight}_{\text{Avg}}$ (None → Dark) | $\text{Whitish/Rust Tint}_{\text{Avg}}$ (None → Very Black) | Clear - Dark |
| TURBIDITY | $\text{None}_{\text{Avg}}$ (None → Faint) | $\text{Very Slight}_{\text{Avg}}$ (None → Extreme) | $\text{Slight to Moderate}_{\text{Avg}}$ (None → Opaque) | Slight |
| SUSPENDED SOLIDS | $2.25\text{mg/l}_{\text{Avg}}$ (0 → 10mg/l) | $47.1\text{mg/l}_{\text{Avg}}$ (0 → 535mg/l) | $190\text{mg/l}_{\text{Avg}}$ (1 → 2260mg/l) | 0.5 - 20mg/l |

(Note: Data within parenthesis indicates the observed parameter extrema.)

Figure 9. **Sprinkler Line Aliquot With Dissolved Gas Release Immediately After Sampling.**

Figure 10. Appearance of Sprinkler Line Sample After Gas Release



that it was not hydrogen sulfide. Rather, the gas was believed to be carbon dioxide supersaturated into the water due to the pressure head. Some of the copper sprinkler line samples also demonstrated a slightly oily odor. This probably could be attributed to steel pipe lines connected ahead of the tested copper location. The circumstance of the oil in the steel lines is discussed later.

Steel Sprinklers

The steel sprinkler pipes rather consistently discharged a dank oily water. As a result, physical contamination of the steel systems was considerably more pronounced. In some cases, the oily turbidity was compounded by a rust-type suspended debris. The presence of this latter material was reflected in the high suspended solids values, averaging 190mg/1, with a 1 to 2260mg/1 range. With solids levels such as these, it would be conceivable that a narrow sprinkler orifice might be clogged during an emergency discharge. This clogging could consequently cause the sprinkler head to fail. Further evaluation of this problem could be pursued using scanning electron microscopy.

The rust type material found in the steel lines was likely generated by deterioration of the iron pipe wall. Further analysis of the iron content of these waters verified the high iron level associated with these solids (see Table 3).

The contaminant oil found in these same lines was probably introduced during the initial sprinkler construction. Oil applied to help with cutting pipe threads would be collected and trapped within the line. Figure 11 roughly depicts the oil-contaminated interior of such a pipe. The non-polar, hydrophobic nature of the oil would cause it to cling to the wall in globules. Whenever the pipeline was tapped, a certain amount of this oil would be drawn from the wall and discharged. However, since these lines are rarely opened or flushed, the oil may linger for

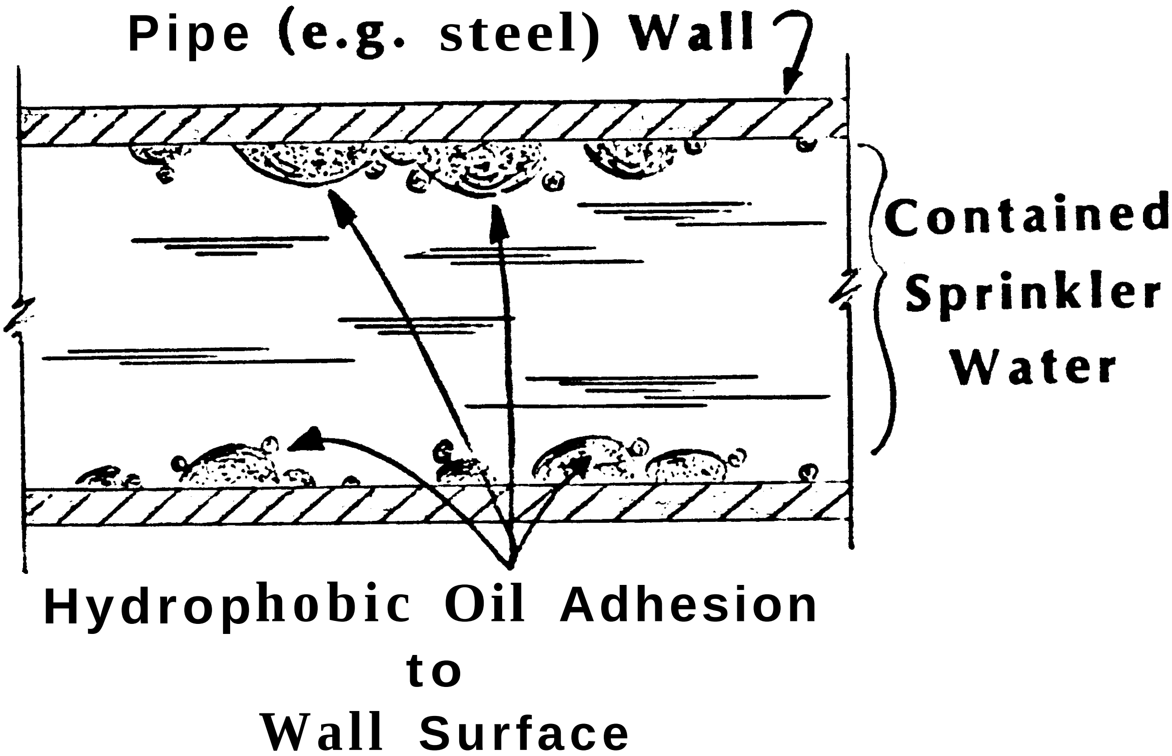



FIGURE 11. **Schematic Depicting Oil Adhesion to the Steel Sprinkler Line Wall**

years. It is unlikely whether this oil could ever be fully expelled from the line without considerable effort.

This oil deposition may actually provide a growth medium for bacteria capable of hydrocarbon degradation. However, such activity is rather unusual in the given anaerobic environment. Hence, although this metabolism is possible, it probably would be insignificant.

As with the copper line samples, an initial dissolved gas released was oftentimes noted immediately after the withdraw1 of the sample. Again, the released gas did not have a foul odor.

Mixed (Copper/Steel) Sprinklers

The remaining two water samples were withdrawn from sprinkler lines which obviously combined both copper and steel construction. The results for these aliquots are consistent with the observations for the majority of the sprinkler samples.

### 5.2.2 Chemical Parameters

Control

The chemical characteristics of the control and sprinkler water samples are summarized by Table 3 with complete information given by Appendix B. The control sample data reflects the general quality expected for a portable water source. The slightly basic pH range and low alkalinity do, however, point towards a possible circumstance of mild pipe corrosion. Although hardness had not been tested during this project, a comparison of sulfate, chloride and specific conductivity values does suggest a low hardness level. These conditions indicate that there is only a nominal potential for desirable calcium carbonate ($CaCO_3$) deposit in the pipeline. This $CaCO_3$ coating would help to prevent pipe walls from chemical corrosion.

TABLE 3

Synopsis of Chemical Characteristics Observed
for Fire Sprinkler Line

| | Control (16 samples) | Copper(Cu) (29 Samples) | Steel(Fe) (25 Samples) | Copper/Steel(Cu/Fe) (2 Samples) |
|---|---|---|---|---|
| pH | 7.8 (7.47 → 8.3) | 7.6 (6.2 → 8.6) | 7.9 (7.3 → 9.15) | 7.9 → 8.4 |
| Alkalinity mg/l as $CaCO_3$ | 7.5 (4 → 14) | 6.7 (3 → 12) | 6 (3 → 9) | 6 → 8 |
| Sulfate, $SO_4^=$ mg/l | 154 (45 → 370) | 114 (27 → 340) | 90 (20 → 340) | 20 → 213 |
| Chloride, $Cl^-$ mg/l | 16.6 (1.5 → 37) | 21.7 (1.5 → 105) | 18.7 (5.5 → 32) | 12 → 20 |
| Ammonia - $NH_4^+$-N mg/l | 0.36 (0 → 0.34) | 2.43 (0.04 → 28) | 1.34 (0.15 → 9.5) | 1 → 1.2 |
| Nitrite/Nitrite, $NO_2^-/NO_3^-$-N | 0 (0 → 0) | 0 (0 → 0) | 0 (0 → 0) | 0 |
| Copper, Cu mg/l | 0.54 (0 → 4.7) | 1.21 (0 → 8.67) | 0.34 (0 → 1) | 0 - 0.7 |
| Cadmium, Cd mg/l | 0 (0 → 0) | 0 (0 → 0.03) | 0 (0 → 0) | 0 |
| Chromium, Cr mg/l | 0 (0 → 0) | 0 (0 → 0) | 0 (0 → 0) | 0 |
| Iron, Fe mg/l | 0.36 (0 → 2.2) | 0.59 (0 → 3) | 8.60 (0 → 145) | 0 - 2.25 |
| Nickel, Ni mg/l | 0 (0 → 0) | 0.04 (0 → 1) | 0 (0 → 0) | 0 |
| Lead, Pb mg/l | 0.04 (0 → 0.5) | 1.78 (0 → 21) | 0 (0 → 0) | 0 |
| Zinc, Zn mg/l | 0 (0 → 0) | 0.92 (0 → 1.67) | 0.40 (0 → 2) | 0 |
| Specific Conductance mhos/$cm^2$ | 202 (118 → 381) | 193 (120 → 437) | 157 (110 → 238) | 114 - 194 |

(Note: Specific numbers are average values. Numbers in parenthesis indicate the observed parameter range)

As for the heavy metals, only copper and iron were present to any significant degree. The occasional presence of either species could be directly related to the pipe line itself, perhaps as a function of the corrosive tendency previously discussed. Neither of these metal contaminants was noted at levels considered extreme according to criteria recommended by the Committee on Water Quality Criteria (55).

Copper Sprinklers

In the case of the copper sprinkler samples, the obtained results were quite interesting. The first four parameters all compared quite closely with the control data. The ammonia-nitrogen ($NH_4^+$-N) values, however, went up noticeably. The average $NH_4^+$-N was 2.43 mg/l, with a range of 0.04 mg/l to 28.0 mg/l. The reason for this elevated ammonium ion presence is unknown. Oxidation of the ammonia was apparently nil, as demonstrated by the zero values for the nitrite and nitrate species.

A couple of the metal values also went up with the copper sprinkler samples. The copper parameter itself went up frequently, with about a two-fold increase in both the average and maximum observed values. Again, copper leachate from the sprinkler accounts for this increase. The other metal species which increased significantly were lead and zinc, With eight samples showing lead readings of 0.5 mg/l or higher, two sample aliquots were alarmingly high at 15 and 21 mg/l respectively (55). The zinc species average 0.92 mg/l, with a maximum value of 1.67 mg/l.

Both of these latter metal forms could possibly be related to the solder forms used in connecting these copper sprinkler lines. Follow-up testing of the solder at the site which yielded the 16 mg/l lead value indicated a 50% lead (Pb) - 50% tin (Sn) composition. This solder form is generally not used exclusively on potable water lines, because of the associated head contact. In some instances, though, it may be used as an exterior cover for an initial

5% antimony - 95% tin soldered connection. The prior use of the 5% - 95% solder negates water contact with lead; the 50% - 50% cover provides additional strength to the fitting.

While a 50% - 50% combination was observed at the sample site, it may conceivably have been underlain by a 5% - 95% form. However, since the sprinkler was not a potable line, the 50% - 50% solder could have been the only form used. A subsequent water re-sampling of this particular sprinkler after 6 months indicated no soluble lead presence. It appeared likely that stagnated sprinkler water in direct contact with a high lead solder may have encountered the metal leaching over an unknown period of time. The flushing provided by the initial sampling probably accounts for the subsequent low-lead result.

Steel Sprinklers

The iron sprinkler systems again had about the same pH, alkalinity, sulfate, chloride, $NO_2^-/NO_3^-$, and specific conductivity as the control samples, although pH did tend to increase somewhat. Ammonia was again higher, with a maximum of 9.5 mg/l and an average of 1.34 mg/l. Again, no explanation can be found for the $NH_4^+$ presence.

Amongst the metal parameters, the iron and zinc values were the only significant variation. The indicated iron average (see Table 3) of 8.60 mg/l was considerably affected by a singular extreme of 145 mg/l. Even disregarding this latter value, the average of 2.3 mg/l is much higher than the control and is considered to be excessive'. This elevated iron presence may be attributable to corrosion of the steel pipes.

With zinc, the observed levels were about the same as with the copper sprinkler lines. In neither case, though, were the zinc levels a serious concern (55).

Mixed (Copper/Steel) Sprinklers

The chemical characteristics of the last two samples for the mixed (Cu/Fe) sprinkler lines were consistent with the preceeding copper and iron pipeline samples. The ammonia values were again seen to be elevated.

5.2.3 Biolonical Parameters

Table 4 provides a synopsis of the results for the biological analyses of the control and sprinkler samples. Complete results are given by Appendix C Of the sixteen control samples taken during the course of the project, seven exhibited virtually no microbial activity during an initial 24 hour period of observation. Additional incubation for 6 to 9 days did occasionally allow for some additional, although minor, growth on the total plate count (55).

However, seven of the control samples had initial total plate counts which were too numerous to count (TNTC). Thus, the range of total count values for the control samples, shown by Table 3, must be qualified. The TNTC plates usually carried discrete pink to red pigmented colonies which would perhaps be appropriate to Serrata colonization (36). Green and white colonies were also noted occasionally. These latter colors were respectively considered appropriate to Pseudomonas and Sarcina (36). The identification of bacterial forms according to pigmentation is, however, rather tentative because of the unstable character of pigment production (56). Elaborate attempts at microbial speciation were not justified, though, for the intent of this project. These particular bacterial forms are quite ubiquitous, and certainly would represent normal contaminant species for such potable water fixtures.

Subsequent efforts were made to characterize possible exterior fixture contamination at selected control sample sites, using sterile swabs to streak TGY plates. Microbial colonization observed on these plates in 1 to 6 days was similar in color and appearance to the control water specimens., None of the sixteen control samples exhibited any fecal coliform growth. And only four samples demonstrated any yeast/mold activity, with all of these below 15 colonies per 100 ml.

The microbial contamination observed with the control sites probably stems from both the water and the fixtures. Although such water contains residual chlorine, it has been established that bacteria may grow in such an environment(57). Indeed, a corroded pipe wall has recently been demonstrated to offer a favorable growth environs for bacterial activity (58).

Copper Sprinklers

Approximately one-half of the twenty-nine copper sprinkler line sample showed virtually no microbial growth over the initial 24 hr period of observation, The remaining samples demonstrated one-day total microbial counts ranging between 1/100ml and TNTC.

Additional growth after a 6 to 9 day incubation period was also evident for many of the plates. In some instances, the counts went from zero to the TNTC value after one week, In general, the total plate colonies were morphologically similar to those witnessed on the control samples (i.e. mostly pink- red colonies, with infrequent green and white growth).

None of the copper line samples produced any indication of fecal coliform contamination, The MFC membrane assay(33) and specific Enterotube II tests (as randomly conducted on total count colonies) were constantly negative. The results for the yeast/mold tests were occasionally positive, although generally nominal in numbers. Only two samples had considerable yeast/mold growth. Continued incubation usually made little difference in the final yeast/mold counts. The observed yeast/mold growths typically yielded a dense mycelial growth with apparent aerial hyphae. These characteristics are consistent with mold species, which are known to be aerophilic in nature. The interior of

## TABLE 4

Synopsis of Biological Characteristics Observed for Fire Sprinkler Line (24 hour incubation values)

| | Sprinkler Pipe Material | | | |
|---|---|---|---|---|
| | Control (16 samples) | Copper (Cu) (29 samples) | Steel (Fe) (25 samples) | ~~Cu/Fe~~ 2 samples) |
| Total Plate Count (#/100ml) | 7 samples@0<br>2 samples@1→25<br>7 samples@TNTC | 13 samples@0<br>9 samples@1→25<br>7 samples@TNTC | 7 samples@0<br>7 samples@1→25<br>4 samples@25→200<br>2 samples@ TNTC | 100→TNTC |
| Fecal Coliform (#/100ml) | -0- | -0- | -0- | -0- |
| Yeast/Mold (#/100ml) | 11 samples@0<br>4 samples@1→25 | 16 samples@0<br>10 samples@1→25<br>3 samples@ TNTC | 9 samples@0<br>6 samples@1→25<br>5 samples@TNTC | 0→TNTC |

the sprinkler would undoubtedly be anaerobic, though. As such, their presence suggests that they were introduced from the exterior surface of the sample site rather that the water itself.

Steel Sprinklers

A comparison of the results shown by Table 4 suggests that the steel sprinkler lines were less contaminated by microorganisms than were the copper lines. Only two of the 25 steel system samples had TNTC total plate counts within a one day incubation period. Three additional TNTC total counts were recorded after 6 to 9 days of growth. The majority of the total plate counts had less than 10 to 20 colonies per 100 ml. In general, all of these colonies appeared similar to the pinkish-red growths seen on the control and copper sprinkler specimens. The steel lines also had an occasional purple-pigmented colony. These growths were believed to be sulfur -related bacteria.

Again, there was no indication of fecal coliform contamination with the steel sprinkler samples. The yeast/mold appearance was also nominal, with most samples ranging between 0 and 5 colonies per 100 ml.

Mixed (Copper/Steel) Sprinklers

The two copper/steel sprinkler lines yielded diverse one-day total plate and yeast/mold counts. Both values on one sample were too numerous to count. The second sample had 100 total count colonies per 100 ml and no yeast/mold. Neither had any fecal coliform contamination.

5.3 Friction Loss Evaluation

A total of 19 tests were conducted to evaluate the friction loss in a section of sprinkler piping. The primary intent of these tests was to collect the necessary data for calculation of the Hazen-Williams 'C' coefficient through application of the equation for friction loss developed by Hazen and Williams. This equation is presented below, in the form stipulating the 'C' coefficient in terms of the other variables:

$$D = \frac{Q}{d^{2.63}(Pf/1)^{.54}}$$

where:

Q = water flow rate (gpm)
d = inside pipe diameter (inches)
Pf = friction loss in pipe section (psi)
L = length of pipe section (ft.)

5.3.1 Discussion of Measurement System

Considering the relatively low flow rates in automatic sprinkler branch lines, a small pressure differential would also be expected. Thus, the level of precision of the measurement system was a primary concern so as not to introduce significant errors. In addition, the measurement system had to be capable of having a fairly rapid response to monitor the transient behavior of the pressure in the branch line.

Selection of an inappropriate measurement system in the initial phase of the project necessitated the discarding of results from numerous tests due to unreasonably large 'C' values, e.g. test 2, as noted in Appendix D. In this initial phase (tests 1 through 2) two Bourdon gages, incremented at intervals of 2 psi, were utilized. As noted in Appendix D, the observed pressure differentialwas only approximately 2 psi. Thus a reading of 2 psi from the gage, actually referred to a pressure between 1 and 3 psi. As such, an error of approximately 25 to 30 percent could be introduced into the determination of 'C'. In addition, the pressure fluctuation caused some difficulty in obtaining an appropriate measure of pressure from the gage, thereby further increasing the error.

Considering the problems noted above, the measurement system for the pressure measurement was altered to include a differential manometer instead of the two Bourdon gages. Thus in tests 9 through 19, the precision of the measurement system was substantially improved. In addition, data were easier to obtain from the manometer than the gages.

An averaging technique was determined to be quite acceptable for meas-

Table 5 Comparison of 'C' Values for Steel and Copper Pipe

| Pipe Material | Avg, 'C' Value | Range |
|---|---|---|
| Steel | 83 | 41 - 135 |
| Copper | 110 | 84 - 125 |

Table 6 Comparison of 'C' Values for Steel and Copper Pipe of Approximate Age of 10 Years

| Pipe Material | Average 'C' Value |
|---|---|
| Steel | 78 |
| Copper | 110 |

Table 7 Comparison of 'C' Values for Steel of Variable Age

| Approximate Age (Years) | Average 'C' Value |
|---|---|
| 5 | 102 |
| 10 | 78 |
| 20 | 92 |

uring the water flow, i.e. an instantaneous flow rate was not observed, but instead the flow rate was determined from the average flow over a 60 second time period. In this manner, the significant dynamic nature of the water flow measurement due to changes in the water supply flow characteristic in the domestic supply was compensated for,

Finally, the measurement of pipe diameter in pipe section length were performed through the use of a tape measure.

5.3.2 Determination of 'C' Factor

As previously stated, determination of the Hazen-Williams 'C' factor was the primary task of the friction loss evaluation phase of the study. The 'C' values were computed utilizing the Hazen-Williams equation relating the 'C' value, friction loss per unit length, elevation change, diameter of pipe and water flow. All tests were conducted on one inch diameter pipe. The data collected from the flow tests and calculated 'C' calues are presented in Appendix D.

The 'C' values can be categorized according to pipe materials and system age. The comparison of calculated 'C' values for steel and copper pipe is presented in Table 5. The data included in the table are from systems of a variety of ages, ranging from five to twenty years. As noted in the table, the average calculated 'C' value by pipe material is larger for the copper than the steel. Also, the lowest and highest calculated 'C' values both resulted from tests conducted with steel pipe. A comparisonof 'C' values for copper and steel pipe of approximately the same age of 10 years is presented in Table 6. This is a more valid comparison and indicates the copper is less affected by corrosion, as is well known.

A comparison of 'C' values for steel of variable age is presented in Table 7. The presented results are contrary to what is generally expected, i.e. a continuing decrease of the 'C' value with age is not indicated in the table. A possible explanation for this apparent discrepancy may be related to to the maintenance program practiced at the test site prior to the conduct of the test. This hypothesis is based on observations from a sequence of three tests each performed at two sites. In this sequence, the first two tests consisted of using relatively low flows. The third test was conducted at a relatively high flow. The results of the two sequences of three tests are presented in Appendix D as tests 14, 15 and 16 and tests 17, 18 and 19.

The remarkable doubling of the 'C' factor from tests 14 and 15 to 16 and 17 and 18 to 19 is attributed to the loosening of some tubercules attached to the inside pipe wall. This loosening of tubercules by a large flow of water was noted in section 3.5 as a technique to decrease the build-up of products of corrosion. Thus, from these two sequences it does appear that routine flushing of sprinkler systems may help control the effects of corrosion. However, it should be remembered that routine flushing is not a panacea. Routine flushing may loosen tubercules and expose a segment of the pipe wall, thereby promoting deterioration of the pipe through corrosion.

Another observation relating to tests 14 through 19 pertains to the different 'C' values for different sections of the same sprinkler system. At low flows the 'C' values are approximately 50 and 65 respectively for the two sections. After flushing, both 'C' values increase to 94 and 135, respectively, however the difference is still very notable.

# VI. DISCUSSION

## 6.1 Water Quality Analysis

### 6.1.1 Physical Sprinkler Water Quality

The sampled sprinkler systems undoubtedly demonstrated physical parameter contamination, although the extent of this problem was quite varied. The steel sprinkler lines represented the extreme, with a generally consistent oil-sediment character. In some cases, the steel sprinkler line samples were opaque. On the other hand, the copper lines showed considerably less disturbance of their physical parameters.

Overall, virtually none of the sprinkler lines produced a water which would be equitable to the physical quality of "drinking water". This degradation is certainly reasonable considering the involved period of stagnation for the the sprinkler lines. And in the case of the steel lines, the introduction of cutting oil during the installation process markedly contributes to the observed levels of physical parameter deterioration. The effect which this physical degradation (i.e. color, turbidity, solids) has on the potability of such waters must, however be qualified as primarily an aesthetic factor, more so than a health-related concern.

### 6.1.2 Chemical Sprinkler Water Quality

For many of the tested chemical parameters, there was essentially no variation between the control samples and the assorted sprinkler lines. Alkalinity, pH, sulfate, chloride, $NO_2^-$-$NO_3^-$-N, and specific conductivity fell within this group. Three of the heavy metal forms also showed no change. These included: chromium, cadmium and nickel.

The remaining chemical parameters demonstrated some degree of deviation from the control status, ranging from nominal to significant differences. Metal contamination of the sprinkler lines was seen to be directly attributable to the system's construction type. The copper lines typically showed an elevated copper concentration, while the steel lines were high in iron. In both cases, the stagnated water appeared to be encountering metal leachate from the pipe wall. Prolonged water stagnation, perhaps compounded by a corrosive circumstance, would certainly have promoted this phenomenon.

The copper sprinkler lines also exhibited an occasional tendency towards lead and zinc contamination. This latter occurrence was believed to depend upon metal leachate from the solders used to connect the copper line. Two specific samples contained lead values of 16 and 21 mg/l. Subsequent re-sampling of these sites six months after their initial sampling and flushing showed no such contamination. Again, the possible occurrence and rate of metal leachate from a soldered site would be directly related to the corrosiveness of the stagnated water. Prolonged contact (i.e. extending several years,) with a lead-containing solder form would conceivably represent a potential problem. The actual rate of metal introduction to the stagnated water, though, would be expected to vary as a function of water chemistry, pipe material, temperature, etc.

The ammonium-nitrogen value was the other chemical parameter which consistently went up for the sprinkler samples. The average concentrations observed with the copper and steel sprinkler lines were, respectively, 2.43 and 1.34 mg/l. There was no apparent reason for this occurrence. While these concentrations are not a problem (i.e. in regards to potability,), the $NH_4^+$ appearance does raise some measure of concern about the actual source of this contaminant.

With the exception of the specific high lead samples, the chemical parameters were not substantially different from the control waters. Additional study might be warranted, however, of the metal leachate reaction, in relation to pipe construction, stagnation period and ambient water character (e.g. corrosiveness).

6.1.3 Biological Sprinkler Yater Quality

Positive results were obtained on more than 50% of the total plate counts taken within any sprinkler category (i.e. copper, steel or mixed lines), as well as the controls. These positives ranged in numbers from a few colonies per 100 ml aliquot to values too numerous to count. As a rough characterization, the copper sprinklers did appear to have less total count activity than the steel lines.

In the vast majority of these growths, the observed colonies demonstrated a pinkish-red pigmentation. While exact identification based on such coloration is tentative, the Serratia form does characteristically fit this description (36). Indeed, Serratia bacteria, as well as Pseudomonas, Flavobacterium, Achromobacter, Proteus, Klebsiella, Bacillus, Corynebacterium, Gallionella and Arthrobacter, have typically been referenced in the context of microbial contamination of water distribution lines (30,(57).

Additional isolation of bacteria from the exterior surfaces of selected control sample sites also showed the pinkish-red total count activity. Certainly it would appear possible that all of the observed microbial contamination might be attributable to an introduction of these exterior species during the sampling effort. In this context, the environment within the sprinkler lines would not appear to be conducive to extensive bacterial growth. Given the prolonged stagnation, anaerobic conditions would prevail and substrate/nutrient availability would be limited.

However, many of the previously mentioned organisms, and particularly Serratia and Pseudomonas, are capable of survival under extreme conditions (i.e. growth in distilled water, etc.). Hence, the conclusion must be drawn that the observed total microbial counts may indeed reflect bacterial activity within the sprinkler lines, above that in the control samples.

As for the fecal coliform assay, none of the seventy-two samples tested during this project ever demonstrated any such contamination.

And finally, the yeast/mold results ranged between 0 and TNTC counts. The control waters were relatively clear, with only 25% of the samples being positive. All of these control counts were below 15 colonies/100 ml. With the sprinkler lines, the copper systems again appeared to have less yeast/mold contamination. In some instances, the observed growth forms were appropriate to aerophilic mold species. This behavior suggests that the contamination was picked up from the sample site surface. However, the obtained yeast/mold data does again point towards possible microbial activity within the sprinkler lines.

## 6.2 Friction Loss Analysis

This analysis of the friction loss characteristics of existing sprinkler pipe in the field yielded a limited amount of quantitative information relative to the deterioration of pipe. More importantly, an appropriate methodology for testing pipe without substantial modification can be suggested. This methodology appears to be sufficiently accurate for the low flows encountered in sprinkler systems and does not require an elaborate measurement system which would be cumbersome, if not impractical for field testing.

This methodology requires the use of a differential manometer to measure the small pressure reduction due to frictional resistance. The tests are optimally performed when the building is uninhabited or when domestic usage is essentially constant, thereby minimizing severe fluctuations in the water supply to the sprinkler system. Because of this problem of fluctuations of the water supply, the averaging technique described previously appears appropriate to minimize the impact of these fluctuations on the measurement,

Problems were encountered with the test procedure in cases where multiple tests were conducted at the same site. These problems resulted from tubercules becoming dislodged at higher flow rates, thereby decreasing the frictional resistance (or increasing the "C" value). Whereas this phenomenon of itself is not a significant problem, the analysis of a series of tests becomes complicated by some test results being from undisturbed pipe and other results from flushed pipe. Subsequent studies should consider this problem and account for the changing characteristics of the pipe.

As previously noted, a major limitation of this study was the inability of this project team to obtain the cooperation of building owners and managers to participate in this study. Before future studies are initiated, consideration should be given to alleviate this problem. This limitation severely restricts this project team from suggesting many significant trends in the data.

In addition to testing existing sprinkler systems in a variety of buildings, it also appears that a variety of positions of the system also should be utilized. The "C" value was observed to vary significantly in two positions of a system included in tests at one position (#14 through #16) and at another position (#17 through #19). It should be noted that the system included in tests #14 through #19 can hardly be considered a large system, implying that significant variations in the "C" value can occur even in relatively small systems.

One trend which does appear from the data accumulated is the lower 'C' value for the steel pipe as compared to the copper pipe. This result is hardly unexpected, yet more testing is required before any firm conclusions can be suggested to confirm that the reduced 'C' value is primarily attributable to the different pipe material and not to other system parameters.

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# Appendix

# APPENDIX

# A

# PHYSICAL WATER PARAMETERS

CONTROL SAMPLES: PHYSICAL PARAMETERS

| Sample Site | Color | Odor | Turbidity | Suspended Solids mg/1 |
|---|---|---|---|---|
| A4 | none | none | none | 0 |
| c2 | none | none | none | 0 |
| D3 | none | none | none | 1 |
| E6 | none | none | none | 5 |
| E11 | none | none | none | 0 |
| F3 | none | none | none | 10 |
| H4 | none | none | none | 1 |
| I2 | none | none | none | 0 |
| J5 | none | none | none | 10 |
| K4 | none | none | none | 0 |
| L4 | none | none | none | 0 |
| M1 | none | none | none | 4 |
| N4 | none | none | none | 4 |
| O4 | none | none | faint | 0.5 |
| Q1 | - | - | - | 0.5 |
| R3 | none | none | slight | 0 |
| maximum | none | none | faint | 10 |
| minimum | none | none | none | 0 |
| average | none | none | none | 2.25 |

COPPER SPRINKLER SAMPLES: Physical Quality

| Sample Site | Color | Odor | Turbidity | Suspended Solids mg/l |
|---|---|---|---|---|
| 10E | slight | none | very slight | 190 |
| 11E | none | slight | none | 9 |
| 13E | none | slight | none | 21 |
| 14E | none | slight | none | 1.5 |
| 15F | none | slight | none | 2 |
| 17F | none | none | none | 21 |
| 21G | none | slight | none | 71 |
| 23H | slight | slight | slight | 535 |
| 251 | none | slight (oil) | none | 13 |
| 261 | slight | (slight) oil | slight | 0 |
| 271 | --- | --- | --- | --- |
| 285 | none | slight (oil) | none | 5 |
| 295 | none | slight | slight | 10 |
| 305 | none | slight (oil) | none | 20 |
| 315 | none | slight | none | 20 |
| 32K | none | none | none | 4 |
| 33K | none | none | slight | 8 |
| 34K | none | none | none | 2 |
| 44N | dark | slight | extreme | 218 |
| 45N | none | slight | slight | 8 |
| 46N | none | slight | very slight | - |
| 470 | slight brown | slight | none | 7 |
| 480 | none | slight | very slight | 8 |
| 49P | none | none | none | 0 |
| 50Q | slight | none | slight | 28 |
| 51R | none | none | none | 0 |
| 54T | none | none | none | 0 |
| 55u | none | none | slight | 2.5 |
| 56U | rusty | slight | extreme | 111 |
| Maximum | dark | slight | extreme | 535 |
| Minimum | none | none | none | 0 |
| Average | slight | slight | very slight | 47.1 |

**STEEL SPRINKLER SAMPLES:** Physical Quality

| Sample Site | Color | Odor | Turbidity | S.S. |
|---|---|---|---|---|
| 1A | - | - | - | 102 |
| 2B | milky-tan | oily-dank | high | 5 |
| 3B | black-grey black | very oily | opaque | 31 |
| 4B | dark brown | dank-rancid | opaque | 900 |
| 5B | light grey | oily | slight | 144 |
| 6B | clear | oily | none | 2 |
| 7c | light tan /light grey | oily/dank | high | 35 |
| 8D | black | oily | - | 78.5 |
| 16F | clear | slight $HCO_3^-$ - like | none | 77 |
| 18F | very dark | oily | opaque | 1.3 |
| 19G | none | none | none | 4 |
| 20G | rusty | oily | - | 36 |
| 22H | very slight reddish | slight oil | slight | 12 |
| 24H | very black | fishy | - | 2260 |
| 35L | whitish tint | none | slight | 7 |
| 36L | whitish tint | none | slight | 79 |
| 37L | none | none | none | 3 |
| 38M | slight rust | none | moderate | 100 |
| 39M | rusty | slight | slight | 450 |
| 40M | rusty | dank | extreme | 215 |
| 41M | slight green tint | some-slight | slight | 20 |
| 42M | none | none | none | 8 |
| 43M | none | none | very slight | 12 |
| 525 | oily/black | oily | - | 159 |
| 535 | cloudy white | faint $CaCO_3$ | none | 1 |
| maximum | very black | oily/dank | opaque | 2260 |
| minimum | none | none | none | 1 |
| average | whitish/rust tint | slightly oily | slight to moderate | 190 |

**COPPER/STEEL SPRINKLER SAMPLES**: Physical Quality

| Sample Site | Color | Odor | Turbidity | S.S. |
|---|---|---|---|---|
| 9D | Clear | Slight oily | slight | 0.5 |
| 12E | dark | oily | slight | 20 |

(NOTE: min/max/avg values are not shown due to the nominal sample count)

# APPENDIX

# B

# CHEMICAL WATER PARAMETERS

CONTROL SAMPLE: CHEMICAL PARAMETERS

| Sample Site | pH | Alkalinity as$CaCO_3$ mg/l | Sulfate $SO_4^=$ mg/l | Chloride $Cl^-$ mg/l | Ammonia $NH_4^+$-N mg/l | Nitrite/Nitrate $NO_2^-/NO_3^-$-N mg/l | Copper Cu mg/l | Cadmium Cd mg/l | Chromium Cr mg/l | Iron Fe mg/l | Nickel Ni mg/l | Lead Pb mg/l | Zinc Zn mg/l | Specific Conductivity mhos/cm² |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A4 | 7.47 | 4 | 72 | 14 | 3.4 | 0 | 0 | 0 | 0 | 0.75 | 0 | 0 | 0 | 134* / 118** |
| C2 | 7.7 | 6 | 185 | 175 | 0.2 | 0 | 0.7 | 0 | 0 | 0.17 | 0 | 0 | 0 | 225 / 216 |
| D3 | 7.8 | 7 | 230 | 5 | 0.3 | 0 | 0.7 | 0 | 0 | 0.33 | 0 | 0 | 0 | 216 / 216 |
| E6 | 7.9 | 10 | 258 | 15.5 | 0.25 | 0 | 0 | 0 | 0 | 0.50 | 0 | 0 | 0 | 200 / 216 |
| E11 | 8.3 | 8 | 220 | 15 | 0.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 215 / 211 |
| F3 | 7.8 | 10 | 175 | 15 | 0.13 | 0 | 0 | 0 | 0 | 0.7 | 0 | 0 | 0 | 210 / 208 |
| H4 | 7.8 | 8 | 190 | 17 | 0.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 215 / 210 |
| I2 | 7.5 | 7 | 140 | 17 | <0.1 | 0 | 0.08 | - | - | - | - | - | - | 199 / 192 |
| J5 | 7.7 | 8.0 | 160 | 12.5 | 0.08 | 0 | 4.7 | 0 | 0 | 2.2 | 0 | 0.5 | 0 | 222 / 220 |
| K4 | 7.7 | 5 | 49 | 15 | 0.08 | 0 | 1 | 0 | 0 | 0.5 | 0 | 0 | 0 | 148 / 142 |
| L4 | 8.2 | 6 | 49 | 15 | 0.08 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 168 / 162 |
| M1 | 7.9 | 5 | 49 | 19 | 0.15 | 0 | 0.5 | 0 | 0 | 0 | 0 | 0 | 0 | 151 / 150 |
| N4 | 8 | 14 | 370 | 37 | <0.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 381 / 380 |
| O4 | 7.8 | 8 | 220 | 30 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 262 / 260 |
| Q1 | 7.5 | 6 | 45 | 18 | 0.18 | 0 | | | | | | | | 143 / 143 |
| R3 | 7.5 | 7.5 | 50 | | 0.08 | 0 | | | | | | | | 172 / 172 |
| maximum | 8.3 | 14 | 370 | 37 | 3.4 | 0 | 4.7 | 0 | 0 | 2.2 | 0 | 0.5 | 0 | 381 |
| minimum | 7.47 | 4 | 45 | 1.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 118 |
| average | 7.8 | 7.5 | 154 | 16.6 | 0.36 | 0 | 0.54 | 0 | 0 | 0.36 | 0 | 0.04 | 0 | 202 |

(*:The top specific conductivity value is for a shaken sample)
(**:The bottom specific conductivity value is for an unshaken sample)

COPPER SPRINKERS SAMPLES : Chemicai Quality

| Sample Site | pH | Alkalinity as $CaCO_3$ mg/1 | Sulfate $SO_4^{=}$ mg/1 | Chloride $Cl^-$ mg/1 | Ammonium $NH_4^+$-N mg/1 | Nitrite/Nitrata $NO_2^-/NO_3^-$-N mg/1 | Copper Cu mg/1 | Cadmium Cd mg/1 | Chromium Cr mg/1 | Iron Fe mg/1 | Nickel Ni mg/1 | Lead Pb mg/1 | Zinc Zn mg/1 | Specific Conductivity $\frac{mhos}{cm^2}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10E | 8.6 | 12 | 300 | - | 28 | 0 | 8.00 | 0 | 0 | 0.50 | 0 | 16.0 | 0.08 | US 40[illegible]<br>S 39[illegible] |
| 11E | 8.0 | 10 | 1C4 | - | 0.6 | 0 | 0.50 | 0 | 0 | 0.50 | 0 | 0.17 | 1.67 | 21[illegible]<br>22[illegible] |
| 13E | 7.8 | 10 | 243 | 75 | 0.25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.08 | 20[illegible]<br>20[illegible] |
| 14E | 7.6 | 8 | 168 | 75 | 0.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0.50 | 0.91 | 19[illegible]<br>19[illegible] |
| 15F | 7.8 | 8 | 138 | 33 | 1.75 | 0 | 0.08 | 0 | 0 | 0 | 0 | 0 | 0.04 | 21[illegible]<br>22[illegible] |
| 17F | 7.3 | 6 | 340 | 80 | 3.1 | 0 | 0 | 0 | 0 | 0 | 0 | 1.67 | 0 | 42[illegible]<br>41[illegible] |
| 21G | 7.1 | 6 | 175 | 105 | 16.6 | 0 | 8.67 | 0 | 0 | 0 | 0 | 0 | 1.67 | 43<br>43 |
| 23H | 6.2 | 3 | 150 | 42 | 29 | 0 | 0.85 | 0.03 | 0 | 0 | 0 | 0 | 0.08 | 20<br>20 |
| 251 | 7.2 | 10 | 27 | 1.5 | 0.5 | 0 | 0.15 | - | - | - | - | - | - | 20<br>20 |
| 261 | 7.5 | 7 | 140 | 3.5 | 0.7 | 0 | 0 | - | - | - | - | - | - | 19<br>19 |
| 271 | - | - | - | - | | - | - | - | - | - | - | - | - | - |
| 285 | 7.6 | 6 | 27 | 5 | 0.33 | 0 | 2.7 | 0 | 0 | 1 | 0 | 0.5 | 0 | 13<br>13 |
| 295 | 8.1 | 5 | 64 | 7 | 0.5 | 0 | 1 | 0 | 0 | 0.5 | 0 | 0 | 0 | 12<br>12 |
| 305 | 7.7 | 6 | 34 | 8 | 0.3 | 0 | 1.5 | 0 | 0 | 1 | 0 | 0.5 | 0 | 13<br>14 |
| 315 | 8.4 | 6 | 42 | 6.5 | 0.5 | 0 | 2.2 | 0 | 0 | 1.5 | 0 | 0.5 | 0 | 12<br>12 |
| 32K | 7.5 | 5 | 57 | 15.5 | 0.5 | 0 | 3 | 0 | 0 | 3 | 0 | 0 | 3 | 14<br>14 |
| 33K | 7.6 | 6 | 79 | 15 | 0.04 | 0 | 1 | 0 | 0 | 0.5 | 0 | 0 | 1.5 | 15<br>15 |
| 34K | 7.7 | 5 | 49 | 17.5 | 1.6 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 14<br>14 |
| 44N | 7.3 | 7 | 199 | 29 | 2.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 21<br>22 |

COPPER SPRINKLERS SAMPLES: Chemical Quality (Cont'd)

| Sample Site | pH | Alkalinity as $CaCO_3$ mg/l | Sulfate $SO_4^-$ mg/l | Chloride $Cl^-$ mg/l | Ammonia $NH_4^+$-N mg/l | Nitrite/Nitrate $NO_2/NO_3^-$-N mg/l | Copper Cu mg/l | Cadmium Cd mg/l | Chromium Cr mg/l | Iron Fe mg/l | Nickel Ni mg/l | Lead Pb mg/l | Zinc Zn mg/l | Specific Conductivity mhos/$cm^2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 45N | 7.3 | 9 | 184 | 14 | 3 | 0 | 0 | 0 | 0 | 0.5 | 0 | 0 | 0 | 226<br>230 |
| 46N | 7.2 | 5 | 72 | 21 | 1.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 149<br>152 |
| 470 | 7.6 | 8 | 60 | 23 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | U 155<br>S 160 |
| 480 | 7.2 | 6 | 100 | 21 | 0.08 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 149<br>151 |
| 49P | 7.5 | 6 | 50 | 18 | 0.16 | 0 | 1 | 0 | 0 | 2 | 1 | 21 | 10 | 140<br>148 |
| 50Q | 7.6 | 5 | 50 | 18 | 0.12 | 0 | 0.5 | 0 | 0 | 1 | 0 | 0 | 1.5 | 141<br>143 |
| 51R | 7.5 | 5 | 45 | 17 | 0.08 | 0 | 1 | 0 | 0 | 0.5 | 0 | 0 | 0.7 | 136<br>137 |
| 54T | 7.6 | 5 | 78 | 16 | 0.05 | 0 | - | - | - | - | - | - | - | 132<br>132 |
| 55U | 7.7 | 6.5 | 75 | 17 | 0.15 | 0 | - | - | - | - | - | - | - | 158<br>160 |
| 56U | 7.6 | 7.0 | 70 | 16.5 | 0.26 | 0 | - | - | - | - | - | - | - | 161<br>161 |
| Maximum | 8.6 | 12 | 340 | 105 | 28 | 0 | 8.67 | 0.03 | 0 | 3 | 1 | 21 | 1.67 | 437 |
| Minimum | 6.2 | 3 | 27 | 1.5 | 0.04 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 120 |
| Average | 7.6 | 6.7 | 114 | 21.7 | 2.43 | 0 | 1.21 | ≃0 | 0 | 0.59 | 0.04 | 1.78 | 0.92 | 193 |

STEEL SPRINKLER SAMPLES: Chemical Quality

| Sample Site | pH | Alkalinity as $CaCO_3$ mg/l | Sulfate $SO_4^=$ mg/l | Chloride $Cl^-$ mg/l | Ammonia $NH_4^+$-N mg/l | Nitrite/Nitrate $NO_2^-/NO_3^-$-N N mg/l | Copper Cu mg/l | Cadmium Cd mg/l | Chromium Cr mg/l | Iron Fe mg/l | Nickel Ni mg/l | Lead Pb mg/l | Zinc Zn mg/l | Specific Conductivity $\frac{mhos}{cm^2}$ Cond. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1A | 8 | 6 | - | 26 | - | 0 | 0 | 0 | 0 | 2.17 | 0 | 0 | 0.66 | US 175<br>S. 190 |
| 2B | 9.15 | 5 | 20 | 15.5 | 1.0 | 0 | 0 | 0 | 0 | 0.92 | 0 | 0 | 0.55 | 110<br>110 |
| 3B | 8.69 | 5 | 20 | 10 | 0.75 | 0 | 0 | 0 | 0 | 4.17 | 0 | 3 | 3 | 110<br>115 |
| 4S | 7.30 | 4 | 72 | 17 | 3.4 | 0 | 0.37 | 0 | 0 | 145 | 0 | 0 | 0.63 | 137<br>146 |
| 5E | 8.02 | 8 | 35 | 7 | 0.9 | 0 | 0.08 | 0 | 0 | 7.83 | 0 | 0 | 0 | 158<br>159 |
| 6B | 7.58 | 5 | 35 | 12 | 1.0 | 0 | 0 | 0 | 0 | 0.17 | 0 | n | 0 | 114<br>114 |
| 7C | 7.8 | 7 | 50 | 5.5 | 0.25 | 0 | 0 | 0 | 0 | 3.92 | 0 | 0 | 1.82 | 130<br>140 |
| 8D | 7.7 | 5 | 87 | 13 | 1 | 0 | 0.08 | 0 | 0 | 7.83 | 0 | 0 | 0 | 117<br>123 |
| 16F | 7.3 | 6 | 340 | 15 | 9.5 | 0 | 0 | 0 | 0 | 0.66 | 0 | 0 | 0 | 186<br>180 |
| 18F | 8.0 | 8 | 250 | 7.5 | 0.25 | 0 | 0.42 | 0 | 0 | 17.00 | 0 | 0 | 0.08 | 216<br>220 |
| 19G | 8.0 | 7 | 109 | 22 | 0.8 | 0 | 0 | 0 | 0 | 0.17 | 0 | 0 | 0 | 195<br>190 |
| 20G | 7.6 | 7 | 123 | 32 | 0.35 | 0 | 0.08 | 0 | 0 | 3.17 | 0 | 0 | 0 | 230<br>238 |
| 22H | 9.0 | 4 | 65 | 23.5 | 1.0 | 0 | 0.05 | 0 | 0 | 0.25 | 0 | 0 | 0.05 | 132<br>139 |
| 24H | 7.8 | 9 | 190 | 11.0 | 0.2 | 0 | 0.35 | 0 | 0 | 3.5 | 0 | 0 | 0.02 | 230<br>220 |
| 35L | 8.3 | 4 | 49 | 16 | 1.5 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 140<br>147 |
| 36L | 8.2 | 4 | 79 | 21.5 | 2.7 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 162<br>169 |
| 37L | 8.8 | 3 | 64 | 16.5 | 0.3 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 142<br>150 |

| Sample Site | pH | Alkalinity as $CaCO_3$ mg/l | Sulfate $SO_4^=$ mg/l | Chloride $Cl^-$ mg/l | Ammonia $NH_4^+$-N mg/l | Nitrite/Nitrate $NO_2^-/NO_3^-$-N mg/l | Copper Cu mg/l | Cadmium Cd mg/l | Chromium Cr mg/l | Iron Fe mg/l | Nickel Ni mg/l | Lead Pb mg/l | Zinc Zn mg/l | Specific Conductivity Cond. mhos/cm2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 38M | 8 | 5 | 64 | 26 | 133 | 0 | 0.5 | 0 | 0 | 0 | 0 | 0 | 1 | US 142<br>S. 148 |
| 39M | 7.8 | 7 | 57 | 23 | 0.15 | 0 | 0.5 | 0 | 0 | 0 | 0 | 0 | 0 | 160<br>165 |
| 40M | 7.7 | 6 | 64 | 21 | 0.37 | 0 | 0.5 | 0 | 0 | 0 | 0 | 0 | 0 | 150<br>152 |
| 41M | 7.7 | 5 | 72 | 23 | 1.4 | 0 | 0.5 | 0 | 0 | 0 | 0 | 0 | 0.3 | 141<br>142 |
| 42M | 8 | 4 | 101 | 25 | 0.75 | 0 | 0.5 | 0 | 0 | 1 | 0 | 0 | 0 | 150<br>150 |
| 43M | 7.4 | 8 | 124 | 32 | 0.16 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 2 | 210<br>212 |
| 52S | 7.3 | 6 | 45 | 24 | 1 | 0 | - | | | | - | - | - | 130<br>131 |
| 53s | 7.5 | 6 | 50 | 22 | 2.2 | 0 | - | - | - | - | - | - | - | 122<br>125 |
| Maximum | 9.15 | 9 | 340 | 32 | 9.5 | 0 | 1 | 0 | 0 | 145 | 0 | 0 | 2 | 238 |
| Minimum | 7.3 | 3 | 20 | 5.5 | 0.15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 110 |
| **Average** | 7.9 | 6 | 90 | 18.7 | 1.34 | 0 | 0.34 | 0 | 0 | 8.60 | 0 | 0 | 0.40 | 157 |

COPPER/STEEL **SPRINKLER** SAMPLES: **Chemical Quality**

| Sample Site | pH | Alkalinity $CaCO_3$ as mg/l | Sulfate $SO_4^=$ mg/l | Chloride $Cl^-$ mg/l | Ammonia $NH_4^+$-N mg/l | Nitrite/Nitrate N mg/l | Copper Cu mg/l | Cadmium Cd mg/l | Chromium Cr mg/l | Iron Fe mg/l | Nickel Ni mg/l | Lead Pb mg/l | Zinc Zn mg/l | Specific Conductivity mhos/cm² Sp. Cond. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 9D | 7.5 | 6 | 20 | 12 | 1 | 0 | 0.7 | 0 | 0 | 0 | 0 | 0 | 0 | US 114<br>S 121 |
| 12E | 8.4 | 8 | 213 | 20 | 1.2 | 0 | 0 | 0 | 0 | 2.25 | 0 | 0 | 0 | 190<br>194 |

**(NOTE: min/max/avg values are not shown due to the nominal sample count)**

# APPENDIX

# C

# BIOLOGICAL WATER PARAMETERS

CONTROL SAMPLES: Biological Quality

| Sample Size | Total Count #/100ml | Fecal Coliform #/100ml | Yeast/Molds #/100ml |
|---|---|---|---|
| A4 | 0@1dy→0@15dy | 0@1dy→0@15dy | 0@1dy→0@15dy |
| c2 | 7@1day | 0@1dy | 0@1dy |
| D3 | 0@1dy | 0@1dy | 1@1dy |
| E6 | 20@1day→20@7dy | 0@1dy→0@7dy | 0@1dy→1@7dy |
| E11 | TNTC@1dy | 0@1dy | 0@1dy |
| F3 | TNTC@1dy | 0@1dy | 0@1dy |
| H4 | 0@1dy | 0@1dy | 0@1dy |
| I2 | TNTC | 0@1dy | 0@1dy |
| J5 | TNTC | 0@1dy | 15@1dy |
| K4 | 0@1dy→6@6dy | 0@1dy→0@6dy | 0@1dy→1@6dy |
| L4 | 0@1dy→12@6dy | 0@1dy→0@6dy | 0@1dy→4@6dy |
| M1 | 0@1dy→TNTC@9dy | 0@1dy→0@9dy | 0@1dy→2@9dy |
| N4 | TNTC@1dy | 0@1dy | 13@1dy |
| O4 | TNTC@1dy | 0@1dy | 0@1dy |
| Q1 | 0@1dy→100@7dy | 0@1dy→0@7dy | 0@1dy→0@7dy |
| R3 | 1@1dy→TNTC@8dy | 0@1dy→0@7dy | 3@1dy→TNTC@7dy |

Note: These results are either for one or more days of incubation.

COPPER SPRINKLER SAMPLES: Biological Quality

| | TOTAL COUNT #/100ml | FECAL COLIFORM #/100ml | YEAST/MOLD #/100ml |
|---|---|---|---|
| 10E | 0@1dy→100@7dy | 0@1dy→0@7dy | 0@1dy→0@7dy |
| 11E | 0@1dy→100@7dy | 0@1dy→0@7dy | 0@1dy→2@7dy |
| 13E | TNTC@1dy | 0@1dy | TNTC@1dy |
| 14E | TNTC@1dy | 0@1dy | 0@1dy→100@7dy |
| 15F | 3@1dy→100@7dy | 0@1dy | 2@1dy |
| 17F | 0@1dy→15@7dy | 0@1dy | 0@1dy |
| 21G | 6@1dy | 0@1dy | 0@1dy |
| 23H | 0@1dy | 0@1dy | 0@1dy |
| 251 | 0@1dy | 0@1dy | 0@1dy |
| 261 | 1@1dy | 0@1dy | 0@1dy |
| 271 | 0@1dy | 0@1dy | 12@1dy |
| 285 | TNTC@1dy | 0@1dy | 3@1dy |
| 295 | TNTC@1dy | 0@1dy | 3@1dy |
| 305 | TNTC@1dy | 0@1dy | 25@1dy |
| 315 | TNTC@1dy | 0@1dy | 25@1dy |
| 32K | 12@1dy→TNTC@6dy | 0@1dy→0@1dy | 2@1dy→TNTC@6dy |
| 33K | 6@1dy→6@6dy | 0@1dy→0@1dy | 0@1dy→15@6dy |
| 34K | 0@1dy→1@6dy | 0@1dy→0@1dy | 0@1dy→1@6dy |
| 44N | 20@1dy | 0@1dy | 16@1dy |
| 45N | 20@1dy | 0@1dy | TNTC@1dy |
| 46N | 20@1dy | 0@1dy | TNTC@1dy |
| 470 | 0@1dy→11@8dy | 0@1dy→0@8dy | 0@1dy→5@8dy |
| 480 | 0@1dy→50@8dy | 0@1dy→0@8dy | 0@1dy→50@8dy |
| 49P | TNTC | 0@1dy→0@8dy | 0@1dy→2@8dy |
| 50Q | 0@1dy→TNTC@8dy | 0@1dy→0@8dy | 0@1dy→9@8dy |
| 51R | 0@1dy→100@8dy | 0@1dy→0@1dy | 0@1dy→@8dy |
| 54T | 0@1dy→2@8 | 0@1dy→0@8 | 0@1dy→5@8dy |
| 55u | 3@1dy→3@8 | 0@1dy→0@8 | 3@1dy→3@8dy |
| 56U | 0@1dy→TNTC@8 | 0@1dy→0@8 | 1@1dy→3@8dy |

STEEL SPRINKLER SAMPLES: Biological Quality

| | TOTAL COUNT #/100ml | FECAL COLIFORM #/100ml | YEAST/MOLD #/100ml |
|---|---|---|---|
| 1A | - | 0@1dy | 3@1dy |
| 2B | 1@1dy | 0@1dy | 0@1dy→50@7dy |
| 3B | 2@1dy→25@6dy | 0@1dy | 0@1dy→0@7dy |
| 4B | 10@1dy | 0@1dy | 0@1dy |
| 5B | >100@1dy | 0@1dy | - |
| 6B | >100@1dy | 0@1dy | 2@1dy |
| 7c | 50@1dy | 0@1dy | - |
| 8D | 50@1dy | 0@1dy | TNTC@1dy |
| 16F | 1@1dy | 0@1dy | 0@1dy→15@7dy |
| 18F | 3@1dy | 0@1dy | 1@1dy |
| 19G | TNTC@1dy | 0@1dy | 5@1dy |
| 20G | 0@1dy | 0@1dy | TNTC@1dy |
| 22H | 0@1dy | 0@1dy | 0@1dy |
| 24H | 0@1dy | 0@1dy | 2@1dy |
| 35L | 0@1dy→TNTC@6dy | 0@1dy→0@6dy | 0@1dy→1@6dy |
| 36L | 0@1dy→100@6dy | 0@1dy→0@6dy | 0@1dy→20@6dy |
| 37L | 0@1dy→TNTC@6dy | 0@1dy→0@6dy | 0@1dy→1@6dy |
| 38M | TNTC@1dy | 0@1dy | TNTC@1dy |
| 39M | - | 0@1dy | TNTC@1dy |
| 40M | 5@1dy | 0@1dy | 8@1dy |
| 41M | 6@1dy | 0@1dy | TNTC@1dy |
| 42M | →TNTC@9dy | 0@1dy→0@9dy | →2@9dy |
| 43M | →1@9dy | 0@1dy→0@7dy | →0@7dy |
| 52S | →1@7dy | 0@1dy→0@7dy | →0@7dy |
| 53S | 0@1dy→0@7dy | 0@1dy→0@7dy | →0@7dy |

**COPPER/STEEL SPRINKLER SAMPLES: Biological Quality**

| Sample Site | Total Count #/100ml | Fecal Coliform #/100ml | Yeast/Mold #/100ml |
|---|---|---|---|
| 9D | 100@1dy | 0@1dy | 0@1dy |
| 12E | TNTC@1dy | 0@1dy | TNTC@1dy |

# APPENDIX D

## LIST OF TEST SITES

List of Sprinkler System Sources for Water
Quality Samples

| | Location | Pipe Material | Months Since Previous Water Flow | System Location For Test | Date |
|---|---|---|---|---|---|
| 1A | Firehouse | St | 30 | H | 3/25/80 |
| 2B | Engineering Labs. | St | 10 | I | 4/8/80 |
| 3B | Engineering Labs. | St | 10 | D | 4/8/80 |
| 4B | Engineering Labs. | St | 10 | V | 4/8/80 |
| 5B | McKeldin Library | St | 10 | I | 4/15/80 |
| 6B | McKeldin Library | St | 10 | D | 4/15/80 |
| 7c | Foreign Language | St | 9 | I | 4/22/80 |
| 8D | Center for Adult Education | St | 10 | D | 4/22/80 |
| 9D | Center for Adult Education | St/Cu | 10 | I | 4/22/80 |
| 10E | #4 Fraternity Row | cu | 12 | H | 5/8/80 |
| 11E | #8 Fraternity Row | cu | 12 | I | 5/8/80 |
| 12E | #9 Fraternity Row | Cu/St | 12 | I | 5/8/80 |
| 13E | #11 Fraternity Row | cu | 12 | I | 5/8/80 |
| 14E | #12 Fraternity Row | cu | 12 | D | 5/8/80 |
| 15F | 7402 Princeton Avenue | cu | 10 | I | 5/8/80 |
| 16F | 4518 Knox Road | St | 12 | I | 5/8/80 |
| 17F | 4514 Knox Road | cu | 12 | I | 5/8/80 |
| 18F | 4531 Knox Road | St | 11 | I | 5/8/80 |
| 19G | 4611 College Avenue | St | 11 | I | 5/13/80 |
| 20G | 4517 College Avenue | St | 12 | I | 5/13/80 |
| 21G | 7407 Princeton Avenue | cu | 12 | I | 5/15/80 |
| 22H | 7511 Princeton Avenue | St | 12 | I | 6/3/80 |
| 23H | 4604 College Avenue | cu | 12 | H | 5/13/80 |
| 24H | 7401 Princeton Avenue | St | 12 | H | 6/3/80 |
| 251 | Leonardtown 238-6 | cu | 60 | H | 6/10/80 |
| 261 | Leonardtown 238-12 | cu | 60 | H | 6/10/80 |
| 271 | Leonardtown 239-12 | cu | 60 | H | 6/10/80 |
| 285 | Leonardtown 243-6 | cu | 60 | H | 6/17/80 |
| 295 | Leonardtown 243-5 | cu | 60 | H | 6/17/80 |
| 305 | Leonardtown 243-2 | cu | 60 | H | 6/17/80 |
| 315 | Leonardtown 243-1 | cu | 60 | H | 6/17/80 |
| 32K | Cambridge Hall | cu | 2 | I | 6/24/80 |

| | Location | Pipe Material | Months Since Previous Water Flow | System Location For Test | Date |
|---|---|---|---|---|---|
| 33K | Cambridge Hall | cu | 2 | I | 6/14/80 |
| 34K | Cumberland Hall | cu | 12 | I | 6/24/80 |
| 35L | Chestertown Hall | St | 12 | I | 7/1/80 |
| 36L | Chestertown Hall | St | 12 | I | 7/1/80 |
| 37L | Bel Air Hall | St | 12 | I | 7/1/80 |
| 38M | Bel Air Hall | St | 12 | I | 7/8/80 |
| 39M | Centreville Hall | St | 12 | I | 7/8/80 |
| 40M | Centreville Hall | St | 12 | H | 7/8/80 |
| 41M | Elkton Hall | St | 12 | H | 7/8/80 |
| 42M | Elkton Hall | St | 12 | H | 7/8/80 |
| 43M | Somerset Hall | St | 2 | I | 7/8/80 |
| 44N | Leonardtown 240-5 | cu | 60 | H | 7/22/80 |
| 45N | Leonardtown 240-2 | cu | 60 | H | 7/22/80 |
| 46N | Leonardtown 241-2 | cu | 60 | H | 7/22/80 |
| 470 | Leonardtown 242-2 | cu | 60 | H | 7/29/80 |
| 480 | Leonardtown 242-1 | cu | 60 | H | 7/29/80 |
| 49P | Hagerstown Hall | cu | 3 | * | 8/12/80 |
| 50Q | Ellicott Hall | cu | 2 | * | 8/12/80 |
| 51R | LaPlata Hall | cu | 1 | * | 8/12/80 |
| 52S | Garden Apartment | St | 60 | H | 8/27/80 |
| 53s | Garden Apartment | St | 60 | H | 8/27/80 |
| 54T | Hagerstown Hall | cu | 1 | * | 9/12/80 |
| 55u | Randallstown | cu | 23 | H | 9/25/80 |
| 56U | Randallstown | cu | 23 | V | 9/25/80 |
| 57v | Chemistry | St | 2 | I | 10/16/80 |
| 57v | Chemistry | St | 2 | D | 10/16/80 |

KEY

1. Pipe Material - Cu Copper
   St Steel
   Cu/St Copper - Steel combination
2. Months since last flush
3. System location for Test
   I - Insp. Test
   H - Sprinkler Head
   D - Drain (Not @ end)
   V - Near Valve
   * - Domestic

List of Sprinkler Systems for Hydraulic Analysis

| Location | Date | Pipe Material | Gage Differential (psi) | Elevation Change (ft) | Flow (gpm) | C |
|---|---|---|---|---|---|---|
| 1. McKeldin Library | 6/12/80 | Steel | ml.0 | 0.25 | 12.5 | 102 |
| 2. McKeldin Library | 6/12/80 | Steel | 0.0 | 0.25 | 12.7 | 369 |
| 3. Cambridge Hall B | 7/80/80 | Copper | 6.0 | 8.0 | 20.7 | 84 |
| 4. Cambridge Hall C | 7/08/80 | Copper | 6.0 | 8.0 | 24.0 | 97 |
| 5. Bel Air Hall | 7/22/80 | Steel | 1.0 | 0.0 | 16.2 | 112 |
| 6. Chestertown Hall | 7/22/80 | Steel | m1.0 | 0.0 | 13.9 | 73 |
| 7. Centreville Hall | 8/07/80 | Copper | 0.0 | 7.33 | 14.6 | 124 |
| 8. Centreville Hall | 8/07/80 | Copper | 5.0 | 7.33 | 18.5 | 95 |
| 9. Parking Garage | 9/18/80 | Steel | 1.03 | 0.0 | 22.2 | 90 |
| 10. Cambridge Hall C | 10/09/80 | Copper | 1.08 | 0.0 | 21.8 | 124 |
| 11. Cambridge Hall C | 10/09/80 | Copper | 1.77 | 0.0 | 26.7 | 117 |
| 12. Cambridge Hall B | 10/16/80 | Copper | 1.33 | 0.0 | 21.2 | 118 |
| 13. Cambridge Hall B | 10/16/80 | Copper | 1.47 | 0.0 | 25.8 | 125 |
| 14. Fire Station - Maintenance Bay | 11/06/80 | Steel | 0.39 | 0.0 | 5.0 | 61 |
| 15. Fire Station - Maintenance Bay | 11/06/80 | Steel | 0.93 | 0.0 | 8.8 | 67 |
| 16. Fire Station - Maintenance Bay | 11/06/80 | Steel | 0.83 | 0.0 | 16.7 | 135 |
| 17. Fire Station - Engine Bay | 11/06/80 | Steel | 1.32 | 0.0 | 7.1 | 41 |
| 18. Fire Station - Engine Bay | 11/06/80 | Steel | 1.86 | 0.0 | 11.5 | 56 |
| 19. Fire Station - Engine Bay | 11/06/80 | Steel | 1.57 | 0.0 | 17.7 | 94 |

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|---|---|---|---|

**4. TITLE AND SUBTITLE**

AN INVESTIGATION OF THE WATER QUALITY AND CONDITION OF PIPE IN EXISTING AUTOMATIC SPRINKLER SYSTEMS FOR THE ANALYSIS OF DESIGN OPTIONS WITH RESIDENTIAL SPRINKLER SYSTEMS

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**10. SUPPLEMENTARY NOTES**

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

**11. ABSTRACT** (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

The objectives of this study were 1) to investigate the potential effect of backflow of sprinkler water into potable water; and 2) to investigate the potential severity of the pressure reduction due to tuberculation in pipes in residential sprinkler systems.

The first objective was achieved by physical, chemical and biological analyses of water samples extracted from existing automatic sprinkler systems. The latter objective was accomplished by calculating the Kazen-Williams 'C' coefficient associated with a measured water flow rate and pressure differential along a sprinkler pipe. Specific sprinkler systems and locations for sampling were selected to provide a wide variety of conditions for the project relative to the study parameters of pipe material, age, size and network configuration.

In particular, this study attempts to compare the quality of water in sprinkler system pipes with that from the potable water supply for the building, The detailed analyses allow relevant and significant comparisons to be conducted to potentially assess the necessity for backflow prevention in residential sprinkler systems. Comparison of the calculated Hazen-Williams coefficient with the coefficient associated with new pipe facilitates an approximation of the degree of tuberculation in the pipe. This result, provides information to assess the severity of pressure reduction as a function of time as affected by the tuberculation and thus to address the useful life of the pipe.

**12. KEY WORDS** (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

corrosion; friction reduction; pipes; potable water; pressure reduction; residential buildings; sprinkler systems; water

**13. AVAILABILITY**

☒ Unlimited
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